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INHERITANCE OF FERTILITY IN SWINE[1]

[PRELIMINARY PAPER]

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INTRODUCTION

Mendelian inheritance applies almost without exception to the transmission of qualitative characters. Quantitative traits, on the other hand, are susceptible only to a generalized treatment from this viewpoint, and few investigators have attacked the problem. Size inheritance in animals has been dealt with by Castle and Phillips (2)[2], Goldschmidt (7), MacDowell (10), Phillips (19, 20), and Punnett and Bailey (21), while Detlefsen (3) has treated the inheritance of certain skeletal characters. Pearl, (15) discovered an arbitrary division point of 30 eggs in the winter laying period of hens, for which inheritance apparently depends on two factors, one of which follows an ordinary Mendelian, and the other a sex-linked scheme. These determiners provide the nearest to units of inheritance that have yet been isolated in quantitative studies.

Because of the fact that fecundity deviates only by discrete units, the litter size in swine provides peculiarly favorable material for studying quantitative inheritance. An analysis of this material has already been attempted from the biometric viewpoint. Rommel and Phillips (24) correlated the size of litters in which dams and daughters were farrowed and found a correlation coefficient of 0.0601 ± 0.0086. They conclude from this result that there is an actual positive correlation between the size of litters of two successive generations, believing that size of litter is a character transmitted from mother to daughter. They recognize the smallness of the coefficient, but believe the indications of inheritance are large enough to provide a basis for selection. In studying fertility inheritance Pearson and Lee (18) obtained practically similar coefficients with the human race and the thoroughbred horse. The range of correlation was 0.0418 to 0.213; hence, they conclude that fertility is certainly and markedly inherited.

[1] Paper No. 1 from the Laboratory of Animal Technology, Kansas Experiment Station.
[2] Reference is made by number to "Literature cited," p. 1159-1163.

Rommel and Phillips (24) studied the inheritance only through the female line, taking no account of a possible influence of the male. George (6) correlated the size of litter with that of the paternal and maternal grandams, respectively. Only 296 litters were involved in his populations; hence, his probable errors were large. But in the dam and daughter comparisons he approximated very closely the result obtained by Rommel and Phillips. His four coefficients follow:

Daughter and dam	0.0615 ± 0.0390
Dam and grandam	$.1147 \pm .0343$
Daughter and maternal grandam	$.0025 \pm .0392$
Daughter and paternal grandam	$.0508 \pm .0392$

None of these correlations are three times as large as their probable error; hence, none are really significant.

Simpson (25) approached the problem from a Mendelian standpoint by crossing a wild German Schwarzwald boar to a young Tamworth sow. The Schwarzwald normally averages 4 pigs to the litter, the Tamworth about 11. The particular sow used was farrowed in a litter of 12 pigs, and to the stint of the wild boar farrowed 9 pigs. In the F_1 generation three females were bred, one to a litter mate and the other two to sires unnamed. The first sow produced 4 pigs, the others 4 and 6, respectively, all in their first litters. The sow producing the 6-pig brood was later served by a pure Schwarzwald boar and farrowed 7 pigs, being apparently constant for that degree of fertility. One of the sows from the brood of 6 gave birth to 12 pigs when mated to a pure Tamworth male. The evidence for a segregation of fecundity factors seems fairly clear, although the numbers are small.

NONGENETIC FACTORS AFFECTING FERTILITY

External factors play a great part in the realization of the inborn hereditary capacity for reproduction. Marshall (12, 13) discusses at length the relation between season and productivity, while the sterility of wild animals in captivity or of domestic animals transferred to vastly different altitudes is proverbial. Marshall and Evvard (4, 5) have both studied the effect of "flushing" in sheep, and Evvard has conducted some very exhaustive investigations into the relation of the various compounds of nutrition to litter size in swine. Using the rate of gain at breeding time in gilts [1] as an indication of the state of nutrition, Evvard has found as much as an average difference of two pigs per litter in favor of the best gainers in each experimental lot, when compared with the poorest gainers. Protein added to a nitrogen-deficient ration (corn alone) produced a marked rise in the fertility of gilts and a medium rise in the fertility of older sows.

Many stockmen believe that overfatness diminishes fecundity. There may be both a physical obstruction of the reproductive organs due to

[1] A gilt is a young sow intended for breeding purposes. The term is usually applied only until the first litter is produced, although it is sometimes extended throughout the suckling period.

fat and an adipose degeneration of the sex glands. Whether these are really causes of decreased fertility is doubtful, since the best evidence shows them to be symptoms of reproductive derangement.

Overfatness occurs frequently as a result of disturbances in the metabolism, due to loss of secretion from several of the ductless glands, the sex gland being here included. Castrating or spaying are known to promote obesity; hence, it is quite reasonable to assume that if testicular or ovarian derangement first occurs, then fat deposition will follow. Overfatness would thus merely indicate and not initiate reduced fecundity.

Market hog raisers usually believe that pure-bred hogs are deteriorating in prolificacy, in line with the common idea that inbreeding ultimately results in barrenness. Bitting, in 1898 (1), investigated the average size of the first 200 litters and the last 200 litters recorded at that time in the herdbooks of the Berkshire, Ohio Poland-China, Standard Poland-China, and Improved Chester White registry associations and found that during the period in which registration had taken place the Berkshires had decreased 0.19 pig per litter, the Poland-China had increased 0.225 pig, and the Chester White had increased 0.1 pig. Rommel (22) investigated the same point for a period of 20 years in books of the American and Ohio Poland-China associations, comparing the average size of litter for the first 5 years with the average for the last 5. The increase was 0.62 pig per litter among the American Poland-Chinas and 0.43 pig per litter in the Ohio strain. A similar study by Rommel (22) on the Duroc-Jersey covering over 15 years showed an increase of 0.57 pig. The changes which have occurred here are manifestly opposed to the idea that purity of blood lines diminishes fertility. On the other hand, the purity of blood can not be credited with the increase, since a constant selection for large litters has taken place, although an increased homozygosis for prolificacy might come about gradually with years of such mass selection as ordinary stock breeding involves.

Hammond (8) has shown that ova may be lost either before or after fertilization; and, still more important, he has discovered that a relatively high percentage may atrophy during the earlier stages of embryonic growth. Lewis (9) indicated that there may be morphological interferences with reproduction, so that fertility may be decreased. He found that the sperm cells of the boar are practically all dead after being in the uterus for 48 hours, which would, of course, result in a reduced fertility. Lewis's results on the viability of sperm differ from those of Dührssen (11), who observed living sperms in the Fallopian tubes of a woman patient three weeks after copulation had taken place. The importance of this question is probably confined to individual cases.

Certain relatively extraneous characters are popularly supposed to be correlated with high fertility. Many farmers believe that "big type" or "cold blooded" hogs farrow larger litters than "hot blooded," or

that "Spotted Poland-Chinas" are far more fecund than ordinary strains. Swine judges commonly consider long-bodied sows more prolific than their chubbier mates. A comparison of 1,000 litters of "large type" Poland-Chinas with 1,100 litters of "small type" showed no significant difference in fertility. The mean for the "large type" was 7.854 ± 0.0456, and for the "small type" was 7.896 ± 0.0436. Furthermore, the standard deviation of the two groups was almost exactly the same, being 2.142 ± 0.0323 for the former and 2.146 ± 0.0309 for the latter. The writers have never seen more than isolated instances brought forward to confirm the popular ideas on this subject and feel that the bulk of such beliefs have resulted from mere advertising schemes.

Breed certainly has its influence. Bitting (1) has averaged the litter sizes for 400 Berkshires, 1,086 Poland-Chinas, and 600 Chester Whites, with the following results:

Berkshire	8.22 pigs per litter.
Poland-China	7.45 pigs per litter.
Chester White	8.96 pigs per litter.

Surface (26) computed the means and standard deviations in the 54,515 litters of Poland-Chinas and the 21,652 litters of Duroc-Jerseys studied by Rommel (22). His constants follow:

	Mean.	Standard deviation.
Poland-China	7.435 ± 0.01	2.038 ± 0.013
Duroc-Jersey	$9.337 \pm .021$	$2.427 \pm .016$

The large numbers here involved undoubtedly prove that real breed differences in fertility exist.

Pearl (15, 16) found the number of mammæ to be correlated positively with the number at a birth when different species are compared, but the coefficient is very low within the species. Parker and Bullard (14) correlated the same characters in 1,000 litters of swine and obtained a coefficient of 0.0035 ± 0.0124. The senior author[1] treated the same point in 170 litters of which he had made genetic studies and obtained a coefficient of -0.0059 ± 0.0517.

These figures certainly demonstrate that the number of mammæ in swine is not related to fertility; in fact, nothing so far discussed presents reliable external characters on which fertility selections can be made. Apparently fecundity has as profound a genetic as physiologic basis.

VALUE OF HERDBOOK DATA

There is now on record an immense mass of data relating to fertility inheritance in swine, in the volumes of the different breed registry associations. In addition to the name and number of the animal, its parents, breeder, etc., the size of litter in which it was farrowed is usually stated.

[1] Unpublished data.

This furnishes opportunity to link together any desired number of generations.

In treating such data, the degree of confidence which can be placed in the figure for litter size must be considered. Its accuracy depends on the carefulness and honesty of the breeder, the accuracy of the clerks in the registry office, and the freedom from typographical errors in the printing of the volume. The matter of personal integrity can be accepted to a high degree, for fortunately the majority of breeders are quite reliable. Whenever falsification wittingly occurs, the tendency is to raise the number per litter; but, owing to the publicity involved in pure-bred breeding as well as the personality invested in breeding animals due to the registry systems, it is doubtful if litter sizes are ever exaggerated by more than one or two pigs.

Investigations in color discrepancies, mistakes in parentage, etc., have shown that about 2 per cent of errors are involved in the work of registry-office clerks and in printing. Some associations are more careful than others, but, of course, none are absolutely free from errors. Unfortunately swine books show a relatively greater number of mistakes than do those published by breeders of some of the other classes of live stock.

However, assuming, as has been done, that the bulk of the records can be accepted, there still remains a question as to their genetic value. It is doubtful whether a sow will ever exceed her hereditary possibilities in number per litter, but there are many forces that may cause her to fall short of that number. Lack of proper nutrition, failure to have all ova released or fertilized, loss of ova, atrophy of fertilized ova or embryos, and disease may all operate against the complete realization of the hereditary make-up. The age at which a sow farrows, the number of litters she has per year, and certain other environmental conditions may also reduce the litter size. It is interesting to observe that this source of error operates in a compensating direction to that of record falsification, when such exists, and in the end the two may counterbalance, although these physiological and pathological factors operate more often than does the misrepresentation of litter numbers.

After admitting all of these sources of error, but hoping that enough records are made under natural conditions to give the figures an investigational value, there still remains the big question of the geneticist, Does the somatic expression of the character indicate the germinal (zygotic) condition of the individual? In other words, Does the fact that a pig is farrowed in a litter of eight indicate that it will transmit a tendency to produce litters of eight? The answer very evidently is No, and the greater the degree of outcrossing in the ancestral lines, the less reliable an index of heredity the size of litter is. Yet it is the only single index obtainable in the study of herdbook records; so for the present it will have to be accepted for what it is worth.

ADVANTAGES OF LITTER SIZE INHERITANCE STUDIES

Accepting the figures for litter size as reasonably representative of the hereditary constitution, there are a number of reasons that make them desirable material for inheritance studies. The most important of these is the fact that the male mated to a female probably does not affect the number at a birth. Instead the size of litters a sow produces represents the segregation of the tendencies transmitted to her by her father and mother. Suppose a sow produces a litter of four pigs and is herself from a litter of seven, the seven does not determine in any way the four, but instead the segregation of some tendency transmitted by her sire or dam is represented. The only check available on this tendency in her sire is the size of litter in which he was farrowed, while the same holds for the dam, except that her own breeding performance may give an additional idea.

METHOD OF RECORDING THE DATA

The data on the animals studied were recorded as follows, the figures representing the size of litters in which the individuals were farrowed:

Animal	Dam	Grandsire / Grandam
		Grandsire 4
4	7	
		Grandam 9

The size of litters produced by sows whose sires came from litters of four and whose dams came from litters of seven should give an idea (through the variations recorded) of the hereditary factors involved. It is admissible that all grandams or all grandsires farrowed in the same size of litters may be different in hereditary make-up, but there should be enough individuals alike to make the frequency curves at least suggestive. For convenience, the grandparental generation will be lettered "P," the parental generation "F_1," and the filial generation "F_2," although it is clearly to be understood that this notation does not have the regular Mendelian significance.

DEVIATIONS PER GENERATION

The mean size of 1,770 litters in the P generation was 7.84 ± 0.3494. The standard deviation was 2.18 ± 0.2461. This gives a coefficient of variability of 27.80 for this generation.

The mean size of 885 litters for the F_1 generation was 7.82 ± 0.4897. The corresponding standard deviation was 2.16 ± 0.3462. The coefficient of variability here involved was 27.60, practically the same as that of the grandparental generation.

The mean size of 885 litters in the F_2 generation was 7.91 ± 0.4965, while the deviation was 2.19 ± 0.3511, giving a coefficient of variability of 27.55. (See Table I.)

TABLE I.—*Deviation in size of litters in swine*

Generation.	Number of litters.	Mean.	Standard deviation.	Coefficient of variability.
P	1,770	7.84±0.3494	2.18±0.2461	27.80
F_1	885	7.82± .4897	2.16± .3462	27.60
F_2	885	7.91± .4965	2.19± .3511	27.55

The mean litter size is quite constant from generation to generation, and furthermore quite close to that obtained by Surface (26) for the breed in general. If anything of Mendelism is involved here, it is not revealed by this method of treatment, for the standard deviation is so nearly the same for each of the generations involved as to give no hint of segregation. In fact, the coefficients of variability would indicate a slowly increasing degree of homozygosis.

Two interpretations may be placed on these figures. The animals studied are either practically constant from a zygotic standpoint, and the variations in litter size are due to environmental treatment, or else there is so much heterozygosis present in the grandparents that the parents are as much F_2 as F_1 in hereditary make-up. For the present the writers are going to use the latter interpretation, as there is no evidence at hand to support a belief in the former.

TABLE II.—*Deviation in litter size of the offspring from the parental generation in swine*

Size of litter of parents.		Number of matings.	F_1 generation.		F_2 generation.	
Boar.	Sow.		Mean.	Standard deviation.	Mean.	Standard deviation.
BOAR 1						
1	9	1	5	0	9	0
1	4	1	2	0	9	0
BOAR 2						
2	5	1	4	0	6	0
2	6	2	8 ±1.43	3 ±1.0117	7.5 ±0.239	.5 ±0.1686
2	8	2	6.5 ± .717	1.5 ± .1737	4 ± .479	1 ± .3372
2	9	1	6	0	6	0
BOAR 3						
3	4	3	7 ±0.171	1.41±0.3433	9 ±1.704	4.32±1.194
3	6	2	6.5 ± .239	.5 ± .1686	8 ± .95	2 ± .674
3	7	4	7.25±1.6218	4.8 ±1.1502	7.75± .8869	2.63± .627
3	11	1	6	0	8	0
3	10	2	10 ± .95	2 ± .674	11	0
3	14	1	11	0	6	0

TABLE II.—*Deviation in litter size of the offspring from the parental generation in swine*—Continued

Size of litter of parents.		Number of matings.	F_1 generation.		F_2 generation.	
Boar.	Sow.		Mean.	Standard deviation.	Mean.	Standard deviation.
			BOAR 4			
4	3	1	8	0	5	0
4	4	3	7.66±1.032	2.62±0.723	8 ±0.631	1.63±0.442
4	5	5	7.2 ± .9951	3.29± .7022	7.6 ± .5202	1.72± .3671
4	6	7	8 ± .2887	1.13± .2037	7.14± .2836	1.11± .2001
4	7	8	8.5 ± .6863	2.42± .408	5.87± .2726	1.14± .1922
4	8	6	7.83± .5390	1.95± .3801	6.83± .7712	2.79± .5438
4	9	6	7.16± .8127	2.94± .5731	7.33± .4008	1.45± .2826
4	10	4	7.25± .5092	1.51± .3618	6.75± .3844	1.14± .2012
4	12	1	7	0	12	0
			BOAR 5			
5	3	1	6	0	12	0
5	4	4	5.75±0.6407	1.92±0.4543	6.5 ±0.3743	1.11±0.2654
5	5	3	7 ± .3195	.81± .2239	6.66± .6666	1.69± .4671
5	6	14	8 ± .3228	1.79± .2282	7.21± .1531	.85± .1083
5	7	12	7.91± .4464	2.29± .358	7.66± .3099	1.59± .2193
5	8	16	7.37± .3979	2.36± .2817	7.56± .408	2.42± .2889
5	9	9	8.11± .3844	1.71± .272	8.22± .5866	2.61± .415
5	10	6	9.33± .5943	2.15± .4191	8.66± .3759	1.36± .2651
5	11	3	6.66± .4891	1.24± .3427	8.33± .3707	.94± .2598
5	12	2	4	0	9	0
			BOAR 6			
6	2	1	7	0	8	0
6	3	3	7.66±0.8283	2.1 ±0.5805	3.33±0.6243	1.58±0.4367
6	4	3	4.66±1.1161	2.83± .7822	9.33± .4391	1.24± .3426
6	5	6	8.6 ± .6041	2 ± .4267	6.83± .4533	1.64± .3197
6	6	11	6.72± .4604	2.26± .3251	8.9 ± .4625	2.27± .3263
6	7	18	7.05± .2672	1.68± .1888	8.5 ± .252	1.86± .178
6	8	24	7.58± .3255	2.36± .2300	7.46± .1862	1.35± .1315
6	9	15	8.4 ± .0046	2.74± .0311	8 ± .047	2.7 ± .0314
6	10	8	6.62± .4657	1.71± .2885	7.87± .6075	2.54± .4283
6	11	5	9 ± .9151	2.32± .6414	5 ± .6922	2.29± .4887
6	12	3	7.66± .1853	.47± .1299	8.33±1.136	2.88± .796
			BOAR 7			
7	3	1	6	0	10	0
7	4	4	7.5 ±0.8431	2.5 ±0.5802	8.5 ±0.1631	5 ±0.119
7	5	7	7.71± .4202	1.62± .292	7.85± .6106	2.39± .431
7	6	17	7.25± .2177	1.33± .1541	7.58± .239	1.46± .1691
7	7	19	7.52± .3023	1.95± .2135	7.42± .3178	2.05± .2244
7	8	26	8.03± .3637	1.99± .1843	7.8 ± .2545	1.92± .1778
7	9	41	9.29± .1958	1.83± .1363	8.82± .2077	1.94± .1445
7	10	8	8.37± .5333	2.23± .3760	6.62± .4610	1.93± .3254
7	11	16	8.5 ± .2596	1.54± .1838	8.43± .4502	2.76± .3187
7	12	6	8.66± .5943	2.15± .4191	6.5 ± .6109	2.21± .4302
7	13	1	10	0	4	0

TABLE II.—*Deviation in litter size of the offspring from the parental generation in swine*—Continued

Size of litter of parents.		Number of matings.	F_1 generation.		F_2 generation.	
Boar.	Sow.		Mean.	Standard deviation.	Mean.	Standard deviation.
BOAR 8						
8	3	7	7.28±0.1124	0.44±0.0793	7 ±0.3193	1.25±0.2254
8	4	8	8.75± .6721	2.81± .4738	7.75± .5572	2.33± .3928
8	5	11	7.33± .2634	1.91± .1861	8.27± .6377	3.13± .4501
8	6	24	6.91± .2965	2.15± .2094	7.66± .3062	2.22± .2161
8	7	29	7.86± .2394	1.91± .1692	7.82± .277	2.21± .1958
8	8	43	6.58± .2519	2.45± .1783	7.23± .2076	2.02± .1469
8	9	34	8.14± .292	2.52± .2124	8.17± .2294	1.98± .1669
8	10	10	6.7 ± .2219	1.04± .1565	8.4 ± .1462	5.37± .8083
8	11	10	7.8 ±1.024	4.8 ± .7225	8.6 ± .512	2.4 ± .3612
8	12	3	9 ±1.4061	3.55± .9895	9.66± .8415	2.04± .5639
8	13	1	9	0	10	0
BOAR 9						
9	2	1	5	0	9	0
9	3	1	5	0	7	0
9	4	6	7.83±0.4616	1.67±0.3254	7.66±0.4616	2.05±0.3996
9	5	12	7.5 ± .3898	2 ± .2758	6.91± .4482	2.3 ± .3172
9	6	7	6.71± .4444	1.74± .3138	7.14± .6065	2.35± .4238
9	7	32	7.59± .2232	1.87± .1576	8.53± .2495	2.09± .1762
9	8	26	7 ± .2663	2.01± .1861	7.5 ± .3074	2.32± .2148
9	9	35	7 ± .3172	2.95± .2377	8.71± .2158	2.10± .1693
9	10	14	8.66± .4060	2.33± .2874	7.53± .3468	1.99± .2453
9	11	8	7.75± .409	1.71± .2883	8.5 ± .526	2.2 ± .3709
9	12	4	8 ± .1686	.5 ± .119	9.25± .3709	1.1 ± .263
9	13	1	7	0	8	0
9	15	1	6	0	8	0
BOAR 10						
10	1	1	8	0	14	0
10	3	2	9 ±0.4781	1 ±0.3372	7.5 ±1.674	3.5 ±1.1803
10	4	2	9	0	7.5 ±1.674	3.5 ±1.1803
10	5	4	7 ± .4755	1.41± .3372	7.25± .4957	1.47± .3516
10	6	6	7.66± .34	1.23± .2397	8 ± .3897	1.41± .2749
10	7	16	7.93± .3591	2.13± .2542	8.18± .4991	2.96± .3533
10	8	24	8.29± .2978	2.16± .2105	8.26± .3787	2.69± .2676
10	9	11	8.9 ± .6153	3.02± .4343	8.63± .3586	1.76± .2531
10	10	14	6.78± .4128	2.29± .2919	7.57± .2777	1.54± .1963
10	11	4	8.25± .435	1.29± .3085	9.5 ± .5598	1.66± .397
10	12	6	8.5 ± .525	1.9 ± .370	8.63± .5888	2.13± .4151
10	14	1	10	0	8	0
BOAR 11						
11	3	1	9	0	10	0
11	4	1	6	0	9	0
11	5	5	6.8 ±0.0574	1.9 ±0.0405	8.2 ±0.5111	1.69 ±0.3607
11	6	6	8 ± .5749	2.08± .4054	6.33± .4644	1.68 ± .3275
11	7	12	7.33± .3004	1.54± .2124	7.85± .3804	2.007± .2705
11	8	4	8.5 ± .1686	.5 ± .1190	8.75±1.2107	3.59 ± .8586
11	9	6	8.83± .6053	2.19± .4269	8.16± .4809	1.74 ± .3391
11	10	6	7.5 ± .3434	1.25± .2422	8.66± .4646	1.69 ± .3277
11	13	1	6	0	12	0
11	15	1	9	0	9	0

TABLE II.—*Deviation in litter size of the offspring from the parental generation in swine*—Continued

BOAR 12

Size of litter of parents.		Number of matings.	F_1 generation.		F_2 generation.	
Boar.	Sow.		Mean.	Standard deviation.	Mean.	Standard deviation.
12	2	1	9	0	7	0
12	4	2	9.5 ± 0.238	.5 ±0.118	8.5 ± 0.238	.5 ±0.118
12	5	2	4 ± .956	2 ± .6745	7	0
12	6	1	8	0	10	0
12	7	5	7.6 ± .554	1.85± .3001	9.2 ± .399	1.32± .282
12	8	6	8.82± .384	1.39± .27	8.5 ± .671	2.4 ± .473
12	9	6	6.5 ± .591	2.14± .414	7.83± .387	1.4 ± .272
12	10	1	11	0	10	0
12	11	2	11	0	8.5 ± .717	1.5 ± .505
12	12	1	10	0	12	0
12	13	2	7	0	9.5 ± .717	1.5 ± .505
			BOAR 13			
13	6	3	8.66± 0.493	1.25±0.345	8.33± 0.185	0.47±0.129
13	8	2	9.5 ± .717	1.5 ± .505	7 ± .956	2 ± .6745
13	9	2	11.5 ± .717	1.5 ± .505	9 ± .956	2 ± .6745
13	11	1	10	0	6	0
13	12	2	7.5 ± .168	.5 ± .245	10 ± .479	1 ± .337
13	13	5	9.6 ± .526	1.74± .371	10 ± .956	2 ± .6745
			BOAR 14			
14	8	2	9	0	10.5 ± 0.239	0.25±0.1686
14	9	1	9	0	11	0
14	12	1	7	0	3	0
			BOAR 15			
15	8	1	12	0	8	0

INDIVIDUAL EVIDENCES OF SEGREGATION

Table II is produced by treating the litter size as a detailed character and comparing the parental generation with offspring. The average of the F_1 deviations is 1.87 ± 0.0549, while the F_2 mean deviation is 1.92 ± 0.0582. The probable errors make these two constants overlap, so that the individual treatment when lumped seems no more significant than when the deviations per generation are considered. Yet many individual evidences of segregation exist, and many times the F_2 generation from a particular cross is so small in numbers that only a fragmentary view of the segregable possibilities is obtained.

While it is possible that 90 per cent of the litter sizes in these tables do not represent the exact genetic constitution, yet it is probable that in general the greater the disparity in litter sizes between the two animals in the P generation, the greater will be the expected deviations in the F_2, and the smaller the deviations in the F_1 generation. The following results, Table III, are produced by tabulating the averages of the deviations on this basis.

TABLE III.—*Average deviations in litter size in the F_1 and F_2 generations of swine*

Difference in number of pigs in the two P litters.	0	1	2	3	4	5	6	7	8
F_1 deviations...........	2.13	1.89	1.93	2.04	2.19	1.82	1.32	1.12	0.5
F_2 deviations...........	1.91	1.84	2.16	2.10	2.16	1.71	1.72	1.98	.5

A calculation of the probable errors involved in this table shows that only the difference between the F_1 and F_2 deviations where the disparity in litter size is seven pigs is large enough to be mathematically significant. The difference when the parents vary from each other by two pigs and by six pigs is on the border line between significance and nonsignificance, but the five other columns are distinctly unenlightening. Yet, if the difference of two pigs is barred, the results are what might be expected.

One criticism against the preceding method of treatment is thoroughly valid. If swine fertility depends on only one or two genetic factors, it is obvious that the point at which the difference between the two parents occurs is more important than the degree of difference. For example, if there is a physiological division point between two hereditary factors at six pigs, then a difference of two or even of four below six pigs might not be significant, while a difference of one more or one less in a litter of six or seven pigs would be thoroughly significant. An examination of the data from this point of view is now in progress, but it is probable that the key to the situation will only be discovered by breeding experiments.

CURVES OF LITTER FREQUENCIES

The distribution of the different sizes of litters in the three generations is given in Table IV.

TABLE IV.—*Litter frequencies in swine*

Generation.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
P Expected......	0.11	1.5	9.8	39	108	216	324	370	324	216	108	39	9.8	1.5	0.11
P Actual.........	3	9	30	80	124	198	300	362	318	162	91	59	20	6	3
F_1 Expected.....	.05	.75	4.9	19	54	108	162	185	162	108	54	19	4.9	.75	.05
F_1 Actual........	0	5	14	32	69	122	149	161	149	85	62	23	8	4	2
F_2 Expected.....	.05	.75	4.9	19	54	108	162	185	162	108	54	19	4.9	.75	.05
F_2 Actual........	0	4	17	32	63	107	154	172	135	95	59	30	11	3	3

Figures 1, 2, 3, and 4 show the curves for the litter frequencies in the three generations and indicate how close the actual numbers of litters come to the binomial curve $(x+y)^{14}$. It is perhaps incorrect to call the theoretical frequencies recorded in Table IV "expectations," unless it is clearly understood that they are the expectations founded on the nearest binomial. There is nothing in the inheritance to make them true expectations from an experimental standpoint.

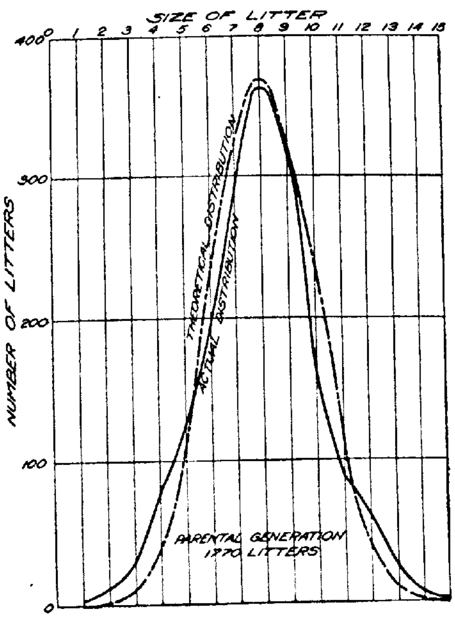

FIG. 1.—Curve of litter frequencies in the P generation of swine.

The curve of the actual distribution spreads out at the extremities much wider than should be expected on a chance basis. This is true in regard to both extremes of the curve and makes it appear as though the curve were compound—i. e., the sum of several curves having separate means from which deviations take place. An analysis on this basis gives two small curves at the extremes, which, while they do not give perfect Gaussian distributions, are characteristic enough to make the assumption of another mean for each perfectly valid. The modes of these three curves are as follows:

Curve 1	4 pigs per litter.
Curve 2	8 pigs per litter.
Curve 3	12 pigs per litter.

It is premature to announce that these modes represent centers of deviation for genetic factors, although a casual observation of the individual data makes it seem that this condition may exist. Furthermore, the mode of curve 1 corresponds to the degree of fertility which Simpson states is characteristic of the wild hog, while the mode of curve 3 is very close to that of the Tamworth, the most fecund of domestic breeds. This indicates that the two may represent basic and improved factors for fertility, respectively, while curve 2 represents heterozygous conditions.

Before these curves can be accepted as more than merely suggestive a further analysis must be made. There is a significant deviation from expectancy in the right-hand branch of the curve of the total population, which persists even after the separation into three curves. In figure 4 this deficiency is located in the left-hand branch of curve 3, but the minus deviations may just as logically belong in the right-hand branch of curve 2, suggesting that it also may be compounded of two curves dependent on a genetic factor not disclosed thus far.

Paralleling this study some actual matings of swine have been planned and are in progress.

SUMMARY

(1) Fertility in swine offers favorable material for the study of quantitative inheritance, because the units of deviation are discrete.

(2) Biometric studies of litter size with mother and daughter have indicated a small degree of inheritance.

(3) Crosses of breeds having different mean

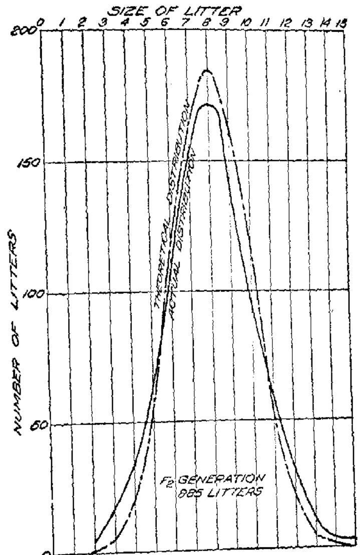

FIG. 2.—Curve of litter frequencies in the F_1 generation of swine.

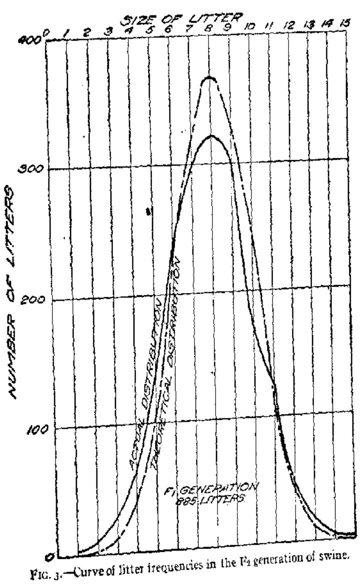

FIG. 3.—Curve of litter frequencies in the F_2 generation of swine.

litter sizes have suggested that segregations of fecundity factors may take place.

(4) Numerous nongenetic factors limit the full expression of the inborn possibilities of fertility.

(5) Certain few somatic characters may be correlated either in a physiological or genetic manner with the different degrees of fecundity, but the bulk of characters usually assumed to be so related are probably entirely independent of it.

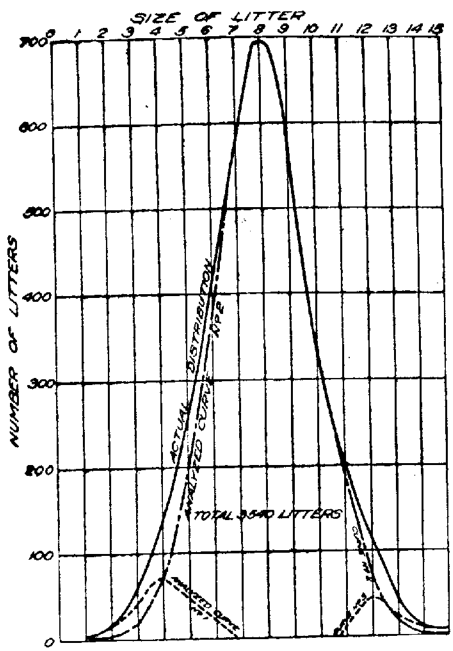

FIG. 4.—Diagram of the combined litter frequencies for the three generations of swine analyzed into its component curves.

(6) Herdbook data on the fertility of swine present sources of error, but the percentage of error is low enough to permit the statistics to be suggestive.

(7) Numerous influences exist which lower the size of litter, which sources of error may operate in a manner compensatory to those just mentioned.

(8) It is questionable whether the size of litter represents the hereditary factors transmitted, but the somatic character was perforce accepted at face value in these studies.

(9) There is no reduction in variability in the litter sizes of the dams as compared with the grandparents or progeny, as would result if there were homozygous differences for fertility in the grandparents. Hence, the fertility deviations are either nongerminal or else the degree of heterozygosis is so great in the grandparents that no increased variability in the F_2 generation is possible. The latter explanation is probably the correct one.

(10) The frequency curves for the 3,540 litters studied make it appear that there are at least three centers of deviation in swine fertility. These centers possibly correspond to genetic factors involved in the inheritance of fecundity.

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RELATION OF GREEN MANURES TO THE FAILURE OF CERTAIN SEEDLINGS

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INTRODUCTION

In a previous report it has been shown that if green manures are turned under and the soil planted immediately, a decrease in germination may result. For example, a 20-acre field, half in crimson clover (*Trifolium incarnatum*) and half in fallow, was plowed and planted to cotton (*Gossypium* spp.) (17, p. 26).[2] On the crimson-clover plot the cotton failed almost completely to germinate. Here and there a few crippled seedlings appeared, while on the fallowed plot normal germination occurred. Seed from the same lot was used on both plots. The green manure in some way seriously affected the germination of the cottonseed. Three weeks later the green-manure plot was again seeded to cotton. Germination at this time was perfectly normal. Apparently the harmful factor disappeared during the interval of three weeks.

A more extensive study of the substances affecting seed germination and of the factors involved was deemed advisable. The controlling idea in this investigation was a study of the effect of green manures on the germination of different seeds. In determining the percentage of germination, only those seedlings that appeared above the surface are recorded.

The amount of green manure used was determined from the following calculation: A good crop of clover should yield from 4 to 5 tons of undried green hay per acre. If 1 acre of soil 3 inches deep weighs 1,000,000 pounds, then 1 per cent of green clover is comparable to the amount employed under field conditions. Except in rare cases this amount of green manure was used in all of the laboratory studies. The green plant tissue was cut just before blooms began to form, finely chopped, and mixed thoroughly with Miami silt loam soil from the Experiment Station farm. The soil moisture was maintained at 50 per cent saturation. All tests of germination are recorded in percentages. Photographs were made of the young seedlings two weeks after planting.

EFFECT OF GREEN MANURES ON THE GERMINATION OF VARIOUS SEEDS

Since it has been shown that seeds of different plants vary widely in chemical composition, it is very probable that they will react differently toward green manures. This experiment was planned to test the effect

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[2] Reference is made by number to "Literature cited," p. 1175-1176.

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of decomposing plant tissue on the germination of buckwheat, castor beans, corn, crimson clover, flax, hemp, lupines, mustard, oats, peanuts, soybeans, sunflower, and wheat. The percentage composition of these seeds is given in Table I.

TABLE I.—*The percentage composition of various seeds* (*11, 20*)

Name.	Fat.	Crude protein.	Nitrogen-free extract.	Crude fiber.	Ash.
Castor bean (*Ricinus communis*)	51.37	18.75	1.5	18.1	
Peanut (*Arachis hypogaea*)	45	25	18		3.1
Flax (*Linum usitatissimum*)	33.7	22.6	23.2	....	2 to 5
Hemp (*Cannabis sativa*)	32.58	18.23	21.06	7.1	4.3
White mustard (*Brassica alba*)	29.66	27.59	20.83	14.97	4.24
Sunflower (*Helianthus annuus*)	28.79	16.3	17.28	10.27	4.47
Cotton (*Gossypium herbaceum*)	20.86	19.69	23.43	27.9	3.3
Soybean (*Glycine soja*)	17.00	35.00	26.00	21.1	3.8
White lupine (*Lupinus albus*)	6.79	28.78	33.65	5 to 6	4.5
Oat (*Avena sativa*)	5.27	10.25	59.68	11.92	2.99
Corn (*Zea mays*)	4.5	9.5	68.5	9.97	3.02
Buckwheat (*Fagopyrum tataricum*)	2.68	11.41	58.79	2.18	1.6
Wheat (*Triticum sativum*)	1.65	10.93	70.01	11.44	2.38
				2.12	1.92

The seeds are grouped according to fat content; those richest in fat are given first. The marked difference in the chemical composition of various seeds is very noticeable. For instance, castor beans contain more than 50 per cent of fat, while oats contain less than 2 per cent.

According to Nobbe (16, p. 173), seeds rich in oil require more oxygen for germination than starch seeds. In Tables II, III, and IV data are presented concerning the effect of green manures on various seeds. In every case the seeds were tested under identical conditions. The figures of Table II show the effect of 1 per cent of green clover on the germination of buckwheat, corn, hemp, lupine, and sunflower.

TABLE II.—*Effect of green clover on the germination of various seeds*

No.	Seed.	Treatment.	Germination. 1 week.	Germination. 2 weeks.	Germination. Relative.
			Per cent.	*Per cent.*	*Per cent.*
1	Buckwheat	None	75	90	100
2	....do	1 per cent clover	90	90	100
3	Corn	None	100	100	100
4	....do	1 per cent clover	95	100	100
5	Hemp	None	95	95	100
6	....do	1 per cent clover	65	65	68
7	Lupine	None	75	80	100
8	....do	1 per cent clover	60	60	75
9	Mustard	None	95	95	100
10	....do	1 per cent clover	55	55	58
11	Sunflower	None	90	90	100
12	....do	1 per cent clover	90	90	100

The average percentage of germination in duplicate pots, after one and two weeks, is recorded in Table II. The last column gives the relation between the treated and untreated seeds. A glance at the figures shows clearly that buckwheat, corn, and sunflower were not injured by green manures. On the other hand, hemp and mustard were seriously injured; the latter showed the greatest loss. Lupines are not so sensitive as mustard or hemp toward green manure, although a slight decrease in germination is noted.

As regards fat content, it will be seen that with the exception of sunflower those seeds rich in oil are the most sensitive to green manuring. The very quick germination of sunflower seed may explain their resistance to the injurious factor.

Table III presents data to show the striking difference in behavior of fat and starch seeds toward green manures. A comparison of the injury resulting from the use of green clover and green oats is made.

TABLE III.—*Effect of green clover and oats on the germination of cottonseed and wheat*

No.	Seed.	Treatment.	Germination.			
			1 week.	2 weeks.	3 weeks.	Relative.
			Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
1	Cotton	None	85	92.5	92.5	100
2	.....do	1 per cent of oats	45	65	65	70
3	.....do	1 per cent of clover	17.5	17.5	17.5	19
4	Wheat	None	95	100	100	100
5	.....do	1 per cent of oats	85	90	90	90
6	.....do	1 per cent of clover	85	85	85	85

The germination of cotton was seriously injured by the presence of green manures; the green clover was much more harmful than oat tissue. Wheat was little affected by the use of green manure. The data confirm the results of the preceding test—that is, that seeds rich in oil are especially sensitive to green manures. It appears that the percentage of injury depends to a certain degree on the source of the plant tissue. Plate LXXXIII, figure 1, is reproduced from a photograph of cotton seedlings two weeks after planting. In order to make the seedlings more visible, a thin layer of white quartz sand was poured upon the surface of the soil.

With soybeans in place of wheat, this experiment was repeated, as shown in Table IV.

TABLE IV.—*Effect of green clover and oats on the germination of cottonseed and soybeans*

No.	Seed.	Treatment.	Germination.			
			1 week.	2 weeks.	3 weeks.	Relative.
			Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
1	Cotton....	None...............	95	100	100	100
2	.....do.....	1 per cent of oats.....	35	35	35	35
3	.....do.....	1 per cent of clover..	....	10	10	10
4	Soybean...	None...............	100	100	100	100
5	.....do.....	1 per cent of oats....	40	40	40	40
6	.....do.....	1 per cent of clover..	30	60	60	60

Here it was again found that the oil seeds are very sensitive to green-manuring. Soybeans are more resistant to this injury than cotton.

As regards the source of the green manure, the results of numerous tests indicate that clover causes a greater loss than oat tissue. An exception to this is found with soybeans (Table IV). No satisfactory explanation has been found for the different action of these two substances. The average of three total-nitrogen analyses shows that clover contains 80.27 per cent of moisture and 4.8 per cent of protein (dry basis). The oats contained 82 per cent of moisture and 3.96 per cent of protein. Chemical analyses fail to disclose any very striking differences between the clover and oat tissue. Indeed, the protein content is nearly the same in both substances. It is possible that the nitrogen of legumes is more available than that of nonlegumes (14). It was noticed repeatedly that clover tissue decomposes more rapidly than oat tissue.

EFFECT OF TIME OF PLANTING AND QUANTITY OF GREEN MANURE ON THE GERMINATION OF COTTON SEED

Ten half-gallon jars were filled with soil and treated as shown in Table V.

TABLE V.—*Effect of time of planting and quantity of clover on the germination of cottonseed*

No.	Treatment.	Germination.							
		Planted immediately.				Planted two weeks later.			
		1 week.	2 weeks.	3 weeks.	Relative.	1 week.	2 weeks.	3 weeks.	Relative.
		Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
1	None..................	90	90	90	100	90	95	95	100
2	0.25 per cent of clover..	60	60	60	66	90	95	95	100
3	0.5 per cent of clover...	50	50	50	55	80	95	95	100
4	1.0 per cent of clover...	35	35	35	38	100	100	100	100
5	2.0 per cent of clover...	......	......	......	......	75	85	85	89
6	3.0 per cent of clover...	......	......	......	......	70	85	85	89

From the data of this experiment it is very evident that the serious injury caused by green manures is only temporary. Two weeks after the green manure was turned under, the conditions that affect seed germination disappeared. Aside from the temporary nature of the injurious agent, it will be seen that the percentage of injury is fairly proportionate to the amount of green clover used. In the presence of 0.25 per cent, the rate of germination was decreased 34 per cent, while more than 1 per cent of green manure entirely prevented germination. A comparison of the effect of green manures in different stages of decomposition on cotton germination is shown in Plate LXXXIII, figures 2 and 3.

FIELD EXPERIMENTS WITH GREEN MANURES

Early in the spring of 1914 a series of plot experiments with various seeds was made. For this purpose a good clover sod from the Experiment Station farm, near Madison, Wis., was chosen. This sod was divided into three equal sections: *A*, Clover; *B*, oats; and *C*, unplanted. The sections were subdivided into six plots, as shown in Table VI. Section *A* was allowed to remain in clover, while *B* and *C* were plowed, section *B* planted to oats, and *C* left without any crop. When the oats in section *B* and the clover in section *A* were partly in bloom, the soil was plowed and prepared for planting. One half of each section was planted immediately, the other half 25 days later. It was arranged to study the effect of clover and oat tissue on the germination of cotton, corn, hemp, oats, and soybeans. The same weight of seed was planted in each plot. The results of this series of tests are given in Tables VI and VII.

TABLE VI.—*Effect of green clover on the germination of various seeds*

No.	Seed.	Planted immediately after turning under.				Germination of seed planted 25 days after turning under.	
		With clover.		Unplanted.		With clover.	Unplanted.
		Seed germination.	Weight.	Seed germination.	Weight.		
			Pounds.		*Pounds.*		
1	Cotton	60	....	91	....	190	210
2	.....do	71	....	129	....	202	218
3	Corn	76	21	79	27	68	75
4	Hemp	Few.	8	Many.	27	1,050	1,130
5	Oats	505	....	474	....	Fine.	Fine.
6	Soybean	58	4	83	5.5	83	88

TABLE VII.—*Effect of oats on the germination of various seeds*

No.	Seed.	Germination of seed.			
		Planted immediately after turning under.		Planted 25 days after turning under.	
		With oats.	Unplanted.	With oats.	Unplanted.
1	Cotton	100	210	134	140
2	....do	117	218	125	131
3	Corn	62	75	72	73
4	Hemp	450	1,130	210	320
5	Oats	Many.	Many.	Many.	Many.
6	Soybean	35	88	39	40

From these tables it will be seen that green manures seriously injure the germination of cotton, soybeans, and hemp, while corn and oats are not affected. The diminished germination is not confined to clover tissue, but is noted with oats. This effect of the plant tissue on germinating seeds is also observed in the weight of harvest. Unfortunately, because of climatic conditions, the cotton could not be grown to maturity. On adjoining plots, where the green manure was allowed to decompose for 25 days before planting, no injury was observed.

The field data show (1) that green manures largely prevent the germination of certain oil seeds, and (2) that the unfavorable condition is only temporary.

NATURE OF THE INJURIOUS AGENT

There are a number of possible causes that might account for the destructive influence of green manures on seed germination:

First, the green manure greatly increases the number and variety of micro-organisms. The organisms on the plant tissue may be harmful, or conditions proper for the development of harmful organisms may arise.

Second, the large gain in number of organisms, after the addition of green manure, results in a possible accumulation of substances toxic to germination—for example, poisonous by-products of decomposition, as alkali or acid.

Third, the rapid multiplication of micro-organisms, which results in an increased metabolism, causes soil oxygen to be consumed and carbon dioxid to be given off. Such loss in oxygen and gain in carbon dioxid might conceivably retard or prevent germination. If it is assumed that oil seeds require more oxygen for germination than starch seeds, the third supposition should apply particularly to seeds rich in fat (16, p. 173).

EFFECT OF SOIL TYPE

In order to ascertain the relation to soil type of the agent causing a decrease in germination, a series of tests was made. Four soil types were used: Colby silt loam, Miami silt loam, Sparta acid sand, and neutral sand. The results of the first test are given in Table VIII.

TABLE VIII.—*Effect of green manure on the germination of cottonseed*

No.	Soil.	Treatment.	Germination. 1 week.	2 weeks.	3 weeks.	Relative.
			Per ct.	*Per ct.*	*Per ct.*	*Per ct.*
1	Colby silt loam (acid)........	None..............	90	90	90	100
2	.....do......................	1 per cent of clover.	35	45	50	55
3	Miami silt loam.............	None..............	75	75	75	100
4	.....do......................	1 per cent of clover.	35	35	35	50
5	Miami silt loam, half sand....	None..............	95	95	95	100
6	.....do......................	1 per cent of clover.	45	45	45	50
7	Sand........................	None..............	80	80	80	100
8	.....do......................	1 per cent of clover.	90	90	90	112
9	Sparta acid sand............	None..............	80	80	85	100
10	.....do......................	1 per cent of clover.	70	70	70	82

For the purpose of securing variation in texture, dilutions with Miami soil and quartz sand were made. From the data obtained, it seems that the property of reducing seed germination is common to both silt loams, but is absent or almost inactive in the sands. Since the relative decrease in germination is approximately the same with Miami or Colby silt loam, it appears that soil reaction is not one of the controlling factors. In neutral or acid sand no decided injury was noted. The results of a second series of tests confirm the above statement. Just why sandy soil should prove less efficient than the loams is not evident from the data, unless it is due to the absence of the injurious factor.

EFFECT OF POSITION OF GREEN MANURE

It was arranged to study the effect on seed germination of plant tissue at different depths. Green clover was added at the rate of 1 per cent. The results secured were as follows: When the green manure was placed in the bottom of the jar, 80 per cent of cotton germinated; in the middle, none germinated; on top, 10 per cent germinated. It is evident that green clover must be in close contact with the seed in order to be effective. This may be shown by wrapping cotton seeds with clover leaves. One or two clover leaves greatly injured seed germination. Plate LXXXIII, figure 4, shows the effect of position of green manure on seed germination.

EFFECT OF INCREASED AERATION

In view of the different action of green manures in compact and open soils, it was decided to make a series of tests under conditions that tend to remove gaseous substances. For this purpose, specially designed jars with openings in their bottoms were employed. By means of a glass tube connected with the bottoms of the jars, air was forced through the soil. In these tests air was allowed to pass through the soil for 20 to 30 minutes every day. A comparison of germination in the aerated and unaerated soils failed to show any difference. Change in soil air did not lessen the injury.

EFFECT OF TEMPERATURE

It is a well-known fact that slight changes in temperature often greatly increase or decrease the growth of micro-organisms. Accordingly a test was made with three variations in temperature.

TABLE IX.—*Effect of temperature on germination of cottonseed*

No.	Treatment.	Temperature.	Germination.		Relative.
			4 days.	8 days.	
		°C.	*Per cent.*	*Per cent.*	*Per cent.*
1	None	25	85	85	100
2	1 per cent of clover	25	55	55	64
3	None	30	95	95	100
4	1 per cent of clover	30	35	35	36
5	None	37	100	100	100
6	1 per cent of clover	37	80	80	80

About 30° C. seems to give the greatest injury; lower or higher temperatures fail to cause so great a decrease in germination.

EFFECT OF CERTAIN DECOMPOSITION PRODUCTS

In the decomposition of plant tissue many substances are liberated—e. g., ammonia and carbon dioxid. The relation of ammonium hydroxid to seed germination has been studied by Bokorny (3; 4, p. 37). He found that small quantities of ammonium hydroxid, 0.02 per cent, greatly retarded the germination of cress. It seems that the active protein of the cell is very sensitive to ammonia.

AMMONIUM HYDROXID

A series of tests was made using from 0.1 to 0.01 per cent of ammonium hydroxid. Four different seeds, cotton, corn, soybeans, and wheat, were allowed to germinate between cloths saturated with the varying concentrations of ammonium hydroxid. It was found that 0.05 or 0.01 per cent proved injurious, while 0.1 per cent prohibited all germination.

Since it was established that ammonia is harmful to seed germination, another test was carried out to study the ammonia produced by microorganisms. The results of this study are shown in Table X.

TABLE X.—*Effect of sugar and of clover on ammonification*

Time in 2-day intervals.	Ammonia nitrogen in 100 gm. of soil.		
	No treatment.	1 per cent of sugar added.	1 per cent of clover added.
	Mgm.	*Mgm.*	*Mgm.*
1	1.98	2.0	3.3
2	....	2.1	4.3
3	....	1.96	2.8
4	....	1.4	2.4
5	....	1.4	2.5
6	1.90	2.5	2.6
Total	....	11.36	17.9

Since ammonia formation is largely a product of bacterial action, it was thought that sugar or green manure would cause an enormous increase in this substance. The data of Table X show a slight gain in ammonia in the treated soils, but the amount is far too small to affect germination seriously

CARBON DIOXID

It was found that carbon dioxid, when added in large quantities, retards germination but does not cause the seeds to decay. As soon as the carbon dioxid is removed, germination proceeds in a normal manner. In Table XI is given the periodic evolution of carbon dioxid from soil treated with 1 per cent of sugar and 1 per cent of clover.

TABLE XI.—*Effect of sugar and clover on carbon-dioxid evolution*

Time in days.	Carbon dioxid in 100 gm. of soil.		
	No treatment.	1 per cent of sugar added.	1 per cent of clover added.
	Mgm.	*Mgm.*	*Mgm.*
1	4.62	22.0	16.02
2	6.82	17.2	12.7
3	9.46	36.52	22.0
4	7.21	37.84	22.75
5	7.57	33.97	22.7
6	7.74	29.35	24.2
7	7.65	26.40	24.42
8	9.68	25.30	22.22
Total	60.75	228.58	167.01

From the data in this table it is evident that the amount of carbon dioxid evolved in the presence of sugar or clover is far too small to exert a marked effect on germinating seeds.

CALCIUM CARBONATE

It is well known that free acids greatly retard or prohibit germination (3; 4, p. 37). Aside from the direct effect on seeds, an acid reaction may favor the growth of injurious micro-organisms. Accordingly, two series of tests were made, using a neutral and an acid soil with varying amounts of limestone ($CaCO_3$). The results of the first test are given in Table XII.

TABLE XII.—*Effect of green clover and calcium carbonate on the germination of cottonseed*

No.	Treatment.	Germination.			
		1 week.	2 weeks.	3 weeks.	Relative.
		Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
1	None	85	85	85	100
2	1 per cent of clover	55	55	55	64
3	1 per cent of clover, 0.1 per cent of calcium carbonate	35	....	....	40
4	1 per cent of clover, 0.2 per cent of calcium carbonate	15	....	....	17
5	1 per cent of clover, 0.5 per cent of calcium carbonate	15	....	....	17
6	1 per cent of clover, 1.0 per cent of calcium carbonate	10	....	....	11

The data show clearly that limestone in concentrations of from 0.1 to 1 per cent seriously injured the germination of cotton. The seedlings from limed soils died during the first or second week. A second test, similar to the above, was carried out, using acid soil. Here again calcium carbonate seemed to stimulate the injurious factor.

EFFECT OF HEAT

The results of previous tests indicate very strongly the biological nature of the factor injurious to germination. For example, reduced germination is largely associated with the first stages of decomposition. Second, the data seem to exclude the possibility of harmful gaseous products. It is conceivable that in the early stages of decomposition green tissue is favorable to the growth of certain organisms injurious to germination. Accordingly, a series of experiments were made in which the amount and form of green manure applied, the seed, and the biological factors were modified. From 1.5 to 3 per cent of green manure was added. To remove the biological factor, the jars and contents were sterilized in the autoclave at 15 pounds' pressure for two hours. The results of this study were recorded by photographs. Reading from left to right (Pl. LXXXIV, fig. 6), the jars were treated as follows: *A*, none,

unsterilized; *B*, 1.5 per cent of green manure, sterilized; *C*, 1.5 per cent of green manure, unsterilized; *D*, 3 per cent of green manure, sterilized; *E*, 3 per cent of green manure, unsterilized. The soil shown in the pots in Plate LXXXIII, figure 5, was treated with green oats, in Plate LXXXIV, figure 6, with green clover. Since the corn and wheat did not show any injury, these illustrations were not reproduced. The data from cotton, clover, and flax are presented in Plate LXXXIV, figures 1, 2, 3, 4, and 5. A glance at the seedlings in the sterilized soil shows conclusively that heat removes or renders inactive the harmful factor. The percentage germination of all crops in the sterilized green-manure soil was equal to that of the untreated controls. Apparently, sterilization has in some way prevented any injury from green-manuring. This is true with 1.5 or 3 per cent of green manure. When repeated, the same results were obtained. These data are given in Table XIII. All of the results point to an injurious agent of biological nature.

TABLE XIII.—*Effect of heat on the germination of cottonseed*

Letter.	Treatment.	Germination.			
		1 week.	2 weeks.	3 weeks.	Relative.
		Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
A	None	95	100	100	100
B	Sterilized	85	85	85	85
C	1 per cent of clover		10	10	10
D	1 per cent of clover sterilized.	80	80	80	80
E	1 per cent of oats	35	35	35	35
F	1 per cent of oats sterilized	85	90	90	90

SOURCE OF INJURIOUS AGENT

When portions of diseased seedlings are used to inoculate sterilized green-manured soil, the germination of oil seeds is greatly reduced. Numerous tests show that the harmful agent is readily transferred. From the data it must be concluded that the injury to seed germination is biological, probably due to bacteria or fungi. To study the nature of the agent, a series of tests was made with different micro-organisms.

EFFECT OF BACTERIA

In this series of tests bacteria from seed, from green manure, and from soil were studied. From the nature of the seed coat of cotton it is no doubt very rich in a number of bacteria. According to plate counts, the number of micro-organisms on cottonseed is over 122,000 per gram, or an average of nearly 11,000 organisms to one seed. A comparison of the germination of cottonseed free of bacteria and with bacteria, in unsterilized green-manured soil, did not disclose any difference in germination. The bacteria were removed (2) by exposing the seed to the action of hot mercuric chlorid ($HgCl_2$) or concentrated sulphuric acid (H_2SO_4). The use of sulphuric acid offers an easy and satisfactory method of

removing micro-organisms from cottonseed. The seeds were placed in a large glass-stoppered bottle containing concentrated sulphuric acid and glass beads. After shaking for two minutes, the seeds were removed with a platinum loop and washed in boiled water. From the data it seems that infection is from some source other than the seed.

It has been shown repeatedly that the addition of green manure to soil is followed by an enormous increase in the number of bacteria. Aside from the increase in bacterial food, the green manure carries with it a great number of bacteria (6, 8, 21). Tests with bacteria-free green manures failed to eliminate the injury.

About 16 pure cultures of bacteria were isolated from diseased seeds and green-manured soil. In order to test the effect of these various micro-organisms on germination, sterilized green-manured soil was inoculated with the various species of bacteria and seeded. The tests were carried out in triplicate, using bacteria-free seed of cotton, peanut, and soybeans. Here, again, bacteria failed to show any effect on the germination of oil seeds. In addition to the pure cultures used in the above experiment, a study was made with four laboratory stock cultures, *Bacillus fluorescens liquefaciens*, *B. subtilis*, *B. mesentericus vulgatus*, and *Streptothrix bucallis*. Heavy inoculations of these organisms did not injure the germination of cottonseed or soybeans. This agrees with the results of earlier workers (12, 13, 15, 18)—that is, bacteria grown on rich nitrogenous media do not injure seed germination. An exception to this is noted with cracked or injured seeds.

EFFECT OF FUNGI

From a study of tests carried out with various combinations of sterilized soil, green manure, and seeds free of micro-organisms, it was found that the harmful factor occurs chiefly in soil. The data in Table XIV show very conclusively the position of injury.

TABLE XIV.—*Effect of fungi on the germination of cottonseed*

No.	Treatment.	Germination.			
		1 week.	2 weeks.	3 weeks.	Relative.
		Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
1	Sterilized soil, 1 per cent of sterilized clover.	20	70	70	100
2	Sterilized soil, 1 per cent of unsterilized clover	15	45	45	64
3	Unsterilized soil, 1 per cent of sterilized clover	....	....	....	....
4	Unsterilized soil, 1 per cent of unsterilized clover	....	....	....	....

It seems that the harmful agent is found both in soil and in plant tissue, although it is much more prevalent in soil. The results of later tests confirm this statement.

According to many investigators, fungi may injure seed germination (1, p. 30–39; 7, 12, 15). For example, Muth (15) found *Aspergillus niger* harmful to the germination of various seeds, while Atkinson (1, p. 30–39) and Bolley (5, p. 25–27) report a destruction of cotton and flax seedlings by species of Rhizoctonia and Fusarium.

Since it is established that certain soil fungi are injurious to very young seedlings, the question arises as to the occurrence and growth of parasitic fungi in green-manured soil. An experimental study of the occurrence of fungi in green-manured soil was made. Microscopical examinations of the diseased seeds showed the presence of many fungi on the primary root tip. Although no systematic study was made, some of the forms showed certain characteristics of the genus Rhizoctonia and others of the genus Fusarium. From portions of the diseased tissue plates were poured. In this way several species of fungi were isolated. These are described under laboratory numbers. All attempts to secure a pure culture of any species of Rhizoctonia failed. The various fungi were used to inoculate large tubes and jars of sterilized green-manured soil. The inoculated soil was planted to bacteria-free cottonseed and soybeans. In the soil cultures no injury to germination was noted, except with culture 1. Here from 75 to 100 per cent of the seedlings were killed. Repeated tests with this unknown culture gave similar results. No injury to corn and wheat was noted from inoculations of culture 1, while soybeans and cotton were quickly destroyed.

Since the diseased root tips showed the presence of a Rhizoctonia-like fungus, it was arranged to study the effect of certain species of Rhizoctonia isolated from other sources. Two strains were employed—one isolated from potatoes, the other from alfalfa. The potato culture was secured from the Department of Plant Pathology of the Wisconsin Experiment Station; the alfalfa culture was supplied by Mr. Fred Jones, of the University of Wisconsin. Table XV gives the results of this test.

TABLE XV.—*Effect of Rhizoctonia spp. on the germination of cottonseed*

No.	Treatment and inoculum.	Germination.			Relative.
		1 week.	2 weeks.	3 weeks.	
		Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
1	None, sterilized. Uninoculated	75	80	80	100
2	1 per cent clover sterilized. Uninoculated	80	85	85	105
3	None, sterilized. Inoculated with *Rhizoctonia* sp. from alfalfa	60	70	70	86
4	1 per cent clover sterilized. Inoculated with *Rhizoctonia* sp. from alfalfa	......	......	......	......
5	None, sterilized. Inoculated with *Rhizoctonia* sp. from potato	80	80	80	100
6	1 per cent clover sterilized. Inoculated with *Rhizoctonia* sp. from potato	85	85	85	105

Rhizoctonia sp. isolated from alfalfa proved fatal to cotton seedlings. Two weeks after inoculation all of the young plants were dead. On the contrary, a species of Rhizoctonia from potato produced no noticeable injury to cotton seedlings. This difference in the action of the two strains of Rhizoctonia is very evident from Plate LXXXIII, figure 6, and the data in Table XV. A species of Rhizoctonia from alfalfa produced nearly the same effect on soybeans as on cotton, while the germination of corn was not affected.

A study of the optimum conditions for the growth of culture 1 and *Rhizoctonia* sp. from alfalfa showed that about 25° to 30° C. is the most favorable temperature for both of these fungi. The results of a previous study indicate that about 25° C. is the optimum temperature for the growth of the harmful factor. From the data as a whole, it seems very conclusive that the fungus of culture 1 and probably other fungi are the causative agents in the destruction of germinating seeds.

DESCRIPTION OF THE INJURY

Examination of the diseased seeds shows that the injurious factor probably does not attack seeds until after germination. Apparently the fungus attacks the primary root soon after germination. This occurs when the primary root is from ½ to 1 cm. long. The hyphæ pierce the walls of the host, entirely envelop the root, and often penetrate deep within the tissue. In the affected region the tissue loses its form, turns brown in color, and soon rots. Under the microscope these diseased seedling roots are surrounded by a dense mantle of hyphæ, which are often brown-colored.

RELATION OF GREEN MANURE TO INJURY OF OIL SEEDS

Although the evidence at hand does not warrant a definite conclusion, the author suggests the following as a possible explanation for the injury: The green tissue furnishes an excellent medium for the development of fungi. This is especially true in the first stages of decomposition. After one or two weeks in the soil the green manure undergoes certain changes which render it unsuited to the growth of the injurious fungi.

Just why oily seeds should be so sensitive to fungi is not known. It is possible that the oil partly changes to fatty acids in the process of germination (9, 10). According to Schmidt (19, p. 300–303), oil and fatty acids favor the growth of certain fungi. The fungus may produce a fat-splitting enzym—for example, lipase. This offers a possible explanation for the selective action of the injurious fungi for oil seeds.

SUMMARY

(1) Green manures may seriously injure the germination of certain seeds.

(2) This injury is brought about by the action of certain parasitic fungi.

(3) In the first stages of decomposition of green clover, numerous fungi develop. Some of these fungi are very destructive to seedlings.

(4) Oil seeds as a class are very easily damaged by fungi. Starchy seeds, on the contrary, are very resistant.

(5) Cotton seed and soybeans are examples of seeds extremely sensitive to green manuring. The germination of flax, peanuts, hemp, mustard, and clover is reduced in the presence of decomposing plant tissue, but not to as great a degree as that of cottonseed or soybeans. The germination of buckwheat, corn, oats, and wheat is not affected by green manures.

(6) The damage to oil seeds from green manures is confined largely to the first stages of decomposition. Experimental evidence shows that two weeks after green manure is added it does not cause any serious injury to the germination of oil seeds.

(7) Small applications of calcium carbonate seemed to increase the injury to germination.

(8) The rate of germination determines to a certain extent the degree of injury. Slow germination is marked by a high percentage of diseased seedlings.

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PLATE LXXXIII

Cotton seedlings, showing the effect of green manures on their growth:

Fig. 1.—*A*, *B*, Control; *C*, *D*, 1 per cent of chopped green oats added to the soil; *E*, *F*, 1 per cent of chopped green clover added to the soil.

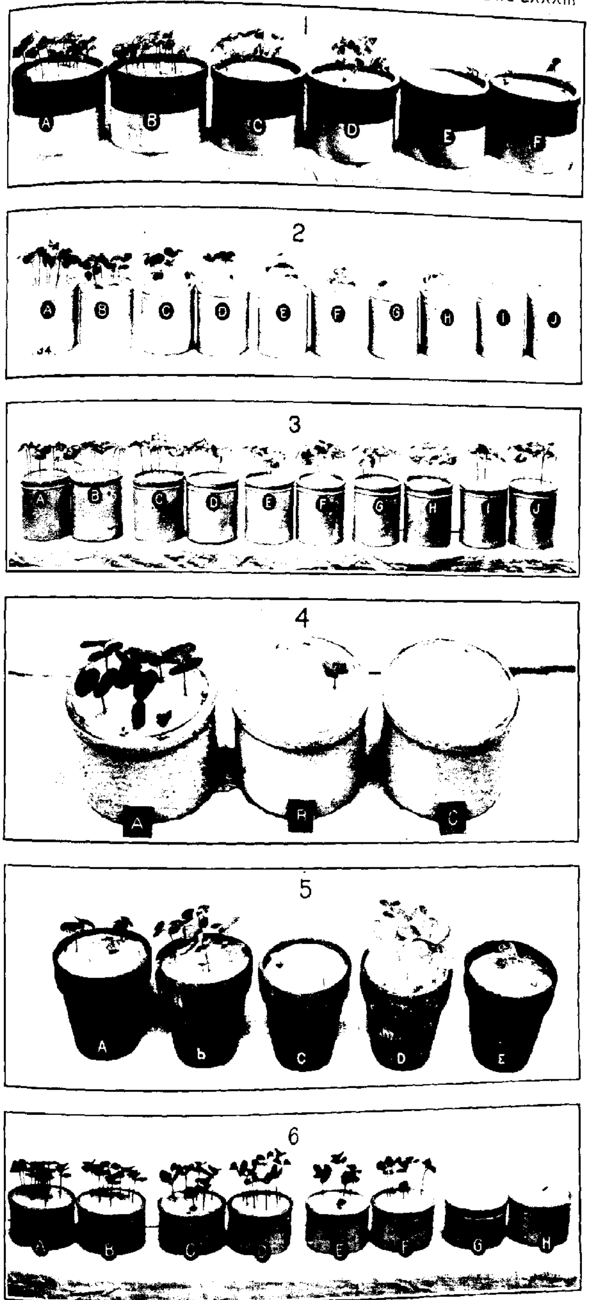
Fig. 2.—Effect of planting immediately after plowing under green manure: *A*, *B*, Control; *C*, *D*, 0.25 per cent of green manure added to the soil; *E*, *F*, 0.5 per cent of green manure added to the soil; *G*, *H*, 1 per cent of green manure added to the soil; *I*, *J*, 2 per cent of green manure added to the soil.

Fig. 3.—Effect of planting 2 weeks after plowing under green manure. *A*, *B*, Control; *C*, *D*, 0.25 per cent of green manure added to the soil: *E*, *F*, 0.5 per cent of green manure added to the soil; *G*, *H*, 1 per cent of green manure added to the soil; *I*, *J*, 2 per cent of green manure added to the soil.

Fig. 4.—Effect of the depth of green manure on germination: *A*, Green manure placed in the bottom of the pot; *B*, green manure placed at the top of the pot; *C*, green manure placed in about the middle of the pot.

Fig. 5.—Effect of sterilized and unsterilized oats used as a green manure: *A*, Control; *B*, 1.5 per cent of oats added and the mixture sterilized; *C*, 1.5 per cent of oats added without sterilization; *D*, 3 per cent of oats added and the mixture sterilized; *E*, 3 per cent of oats added without sterilization.

Fig. 6.—Effect of *Rhizoctonia* sp. on germination in the presence of green manure: *A*, *B*, Control; *C*, *D*, sterilized soil treated with green manure; *E*, *F*, sterilized soil inoculated with *Rhizoctonia* sp. from potatoes; *G*, *H*, sterilized soil treated with green manure and inoculated with *Rhizoctonia* sp. from alfalfa.


1
A B C D E F
2
A B C D E F G H I J
3
A B C D E F G H I J
4
A B C
5
A b C D E
6
A B C D E F G H

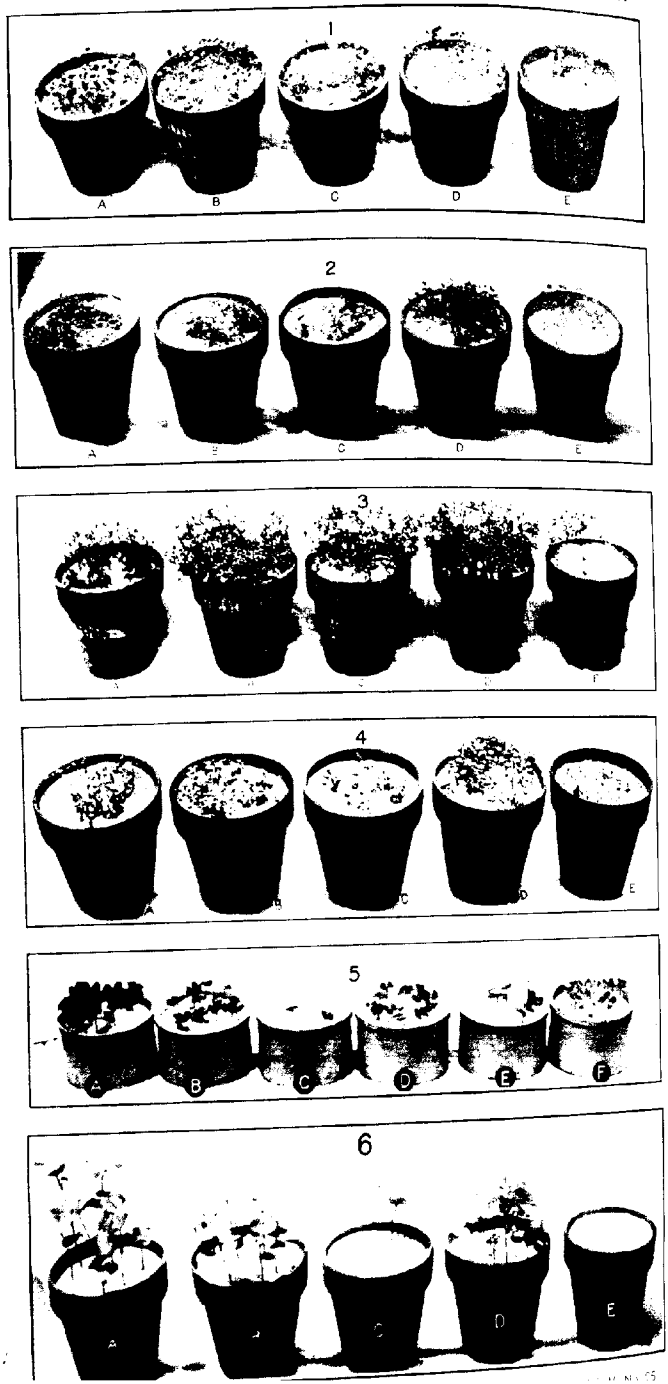


PLATE LXXXIV

Clover, flax, and cotton seedlings, showing the relation of green manures to germination in sterilized and unsterilized soil:

Fig. 1.—Clover: *A*, control; *B*, 1.5 per cent of chopped green oats added and the mixture sterilized; *C*, 1.5 per cent of chopped green oats added and the mixture not sterilized; *D*, 3 per cent of chopped oats added and the mixture sterilized; *E*, 3 per cent of chopped oats added and the mixture not sterilized.

Fig. 2.—Clover: *A*, control; *B*, 1.5 per cent of chopped clover added to the soil and the mixture sterilized; *C*, 1.5 per cent of chopped clover added to the soil and the mixture not sterilized; *D*, 3 per cent of chopped clover added to the soil and the mixture sterilized; *E*, 3 per cent of chopped clover added to the soil and the mixture not sterilized.

Fig. 3.—Flax: *A*, control; *B*, 1.5 per cent of chopped oats added to the soil and the mixture sterilized; *C*, 1.5 per cent of chopped oats added to the soil and the mixture not sterilized; *D*, 3 per cent of chopped oats added to the soil and the mixture sterilized; *E*, 3 per cent of chopped oats added and the mixture not sterilized.

Fig. 4.—Flax: *A*, control; *B*, 1.5 per cent of chopped clover added and the mixture sterilized; *C*, 1.5 per cent of chopped clover added to the soil and the mixture not sterilized; *D*, 3 per cent of chopped clover added to the soil and the mixture sterilized; *E*, 3 per cent of chopped clover added to the soil and the mixture not sterilized.

Fig. 5.—Cotton: *A*, control; B, soil sterilized; *C*, 1 per cent of chopped clover added to the soil and the mixture not sterilized; *D*, 1 per cent of chopped oats added to the soil and the mixture not sterilized; *E*, 1 per cent of chopped clover added to the soil and the mixture sterilized; *F*, 1 per cent of chopped oats added to the soil and the mixture sterilized.

Fig. 6.—Cotton: *A*, control; *B*, 1.5 per cent of chopped clover added to the soil and the mixture sterilized; *C*, 1.5 per cent of chopped clover added to the soil and the mixture not sterilized; *D*, 3 per cent of chopped clover added to the soil and the mixture sterilized; *E*, 3 per cent of chopped clover added to the soil and the mixture not sterilized.

A NEW SPRAY NOZZLE

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INTRODUCTION

A new principle has been discovered in nozzle construction whereby a flat spray can be produced with a uniform distribution of the water comparable to that of the hollow cone of spray from a cyclone nozzle. Hitherto all flat sprays have been of lenticular section, breaking up into fine mist on the sides and into relatively coarse drops in the center. It was observed that the flat spray produced by two impinging streams was at right angles to the original plane of motion of the two streams, but when the streams failed to meet squarely the plane was shifted and could, in fact, be moved through an arc of 180° with a very great change in the distribution of the water currents. It requires only a slight angular deviation to decrease very perceptibly the coarseness of the central drops, producing greater uniformity, and a position can be reached in which the coarsest drops are on the edge, those in the center therefore being the finest.

The principle finally discovered was that when two streams meet across half their section the resulting sheet of spray will be of practically uniform thickness throughout, occupying a plane 45° from the plane of the streams and finally breaking up into drops of great fineness and uniformity.

PRODUCTION OF SPRAY

There are two causes that may act in the production of spray particles: (1) Friction, which may cause an eddy along the edge of the stream sufficient to break the surface tension and allow the small eddying masses to fly off from the column of water; and (2) divergence of the direction of motion of the particles, resulting in the thinning out of the water mass in the form of irregular sheets until the surface film finally gives way and the sheet of water is suddenly converted into drops.

Both methods may be seen in the breaking up of the stream from a simple nozzle where, from the sides of the solid column of water, very minute particles of mist are given off, while the velocity and friction are great. With decreasing velocity farther on the eddies become larger, the mist gradually becomes coarser, and, finally, as the spread of the stream makes it break up into irregular sheets of water, the size of the drops produced by the second process results in an intermingling of drops of all sizes. At first the drops are very accurately graduated,

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those of the same size being produced at the same distance from the nozzle, but when the second process replaces friction as a cause of spray production, irregularity results, owing to the irregular shapes of the water sheets.

In a cyclone nozzle the stream at once diverges widely in the form of a hollow cone. Friction plays no part in the production of the spray, but the cone increases so rapidly in diameter that the liquid soon becomes a very thin sheet of unvarying thinness all the way around, and breaks into a uniformly fine mist. The uniformity may be assumed from the fact that on all sides the sheet extends an equal distance from the orifice before breaking into a spray, and experimentally can be shown to exhibit to an equally high degree both fineness and uniformity.

Figure 1 expresses in a diagrammatic form the facts shown by the photographs. The circles show the actual positions of the orifices in

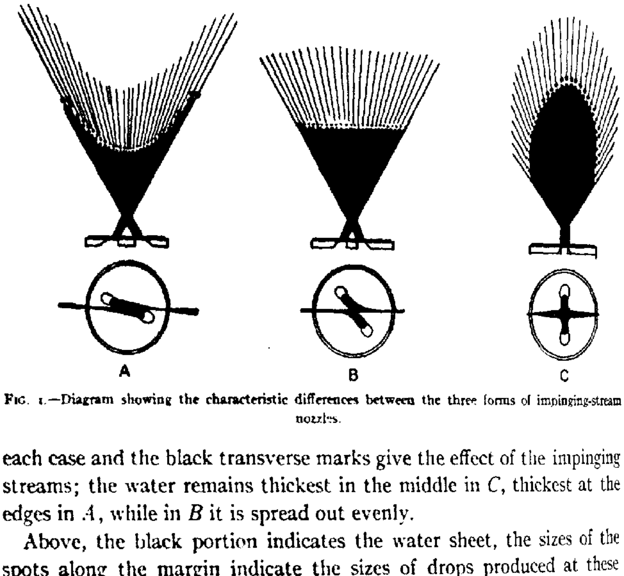


FIG. 1.—Diagram showing the characteristic differences between the three forms of impinging-stream nozzles.

each case and the black transverse marks give the effect of the impinging streams; the water remains thickest in the middle in C, thickest at the edges in A, while in B it is spread out evenly.

Above, the black portion indicates the water sheet, the sizes of the spots along the margin indicate the sizes of drops produced at these points, and the approximate velocity of the drops is shown by the length of the lines radiating from these spots.

SPRAYS PRODUCED BY IMPINGING STREAMS

The actual movement of the water in forming a spray through the impact of two streams is shown in Plate LXXXV and Plate LXXXVI, figure 1 It was not found practicable to secure the successive pictures with sufficient rapidity to show more than two steps in the forming spray, but by interpolating, a fairly satisfactory series was obtained. The

right-hand nozzle is of the common type where the streams impinge squarely. The middle nozzle is of the new type, but not strictly comparable with the former, since the streams come together at a broader angle, making a wider spray. Indeed, when the spray is under full pressure (Pl. LXXXVI, fig. 1) the spread is too wide, producing a lateral dribble and marginal fringe of spray. The left-hand spray is intermediate in angle and spread and gives the fish-tail effect.

The contrast is shown from the first illustration, the fish tail having thick marginal zones and the other two thick central zones, much shorter in the middle nozzle. In Plate LXXXVI, figure 1, where the spray sheets assume their normal proportions under high pressure, the large size of the white patch in the middle corresponds to the better final distribution of the spray particles. The irregularity of the spot shown on the left of this white patch is due to an irregularity in the orifice on the opposite side.

In Plate LXXXVI, figure 2, which shows the result of a sudden decrease of pressure, the character of the water sheets becomes especially evident, since they are increased greatly in size and the production of spray almost ceases.

ADVANTAGE OF A FLAT SPRAY

The cyclone nozzle leaves nothing to be desired in the way of fineness and uniformity of spray, but it has the disadvantage of making a ring of spray which surrounds instead of touching the object towards which the nozzle is directed. It is very difficult for one handling the nozzle to keep in mind the fact that the spray is strictly limited to the visible parts of the cone. A flat spray, on the other hand, reaches the point aimed at and is more available for treating branches of trees, for example, where the desire is to concentrate the spray on a line. For general spraying also the use of a flat spray, like the use of a flat brush for painting, gives uniform results more quickly and easily. For these reasons, while no other nozzle on the market produces a flat spray comparable in quality to the spray produced by the various types of cyclone nozzles, they are, nevertheless, more extensively used than the cyclone nozzles.

ADVANTAGE OF UNIFORMITY AND FINENESS

The use of nozzles of the flat type is generally acknowledged to be for the purpose of securing the flat shape of spray fan and is not a rejection of the principle that a uniformly fine spray is the most desirable. In fact, the use of these nozzles is generally associated with the use of high pressures, whereby the defects of a poor grade of nozzle are less apparent. The particular advantage of fineness is that it makes possible the even distribution of the spray material.

Fineness involves evenness. In a nozzle giving coarse drops, part of the material is in a finely divided state, and the improvement in a spray

nozzle comes through decreasing the size of all but the smallest particles and thus increasing the proportion of minute particles until, as in the cyclone nozzle, practically all of the material is in the most finely divided state and is therefore also uniform. This improvement can be produced by increasing the pressure or decreasing the size of the stream. Under the same pressure a nozzle with a large orifice gives coarser drops than a similar nozzle with a small orifice. Therefore, where a larger volume of spray is desired, it has been the practice to duplicate the nozzles rather than enlarge them, giving clusters of nozzles; but where high pressure is available, large nozzles, particularly those of the better type, may be used. With extreme pressures, such as were employed in the gipsy-moth work and in the walnut spraying in California, a nozzle of the poorest quality and rather large size has proved to be practical. In nearly all cases the desirability of fine and uniform sprays, in order to secure evenness of distribution, has been recognized. It is possible, however, that under some circumstances a driving spray may be desirable, and this can be secured only by the use of less efficient nozzles.

VARIATION IN FINENESS

The sizes of the smallest drops in a spray are not necessarily the same, particularly when made by the breaking up of a sheet of water. By a change in the proportions of the eddy chamber in a cyclone nozzle or by a change in spraying pressure the diameter of the cone at the point of breaking can be changed, and the drops will remain uniform, but will be of a different size than before. In the new type of nozzle here described the angle of impact and the spraying pressure exert similar effects, and a series of nozzles can be produced covering much the same range obtainable in a cyclone nozzle and distinguishable by the width and length of the fan.

Only relatively small drops in the spray in either case are obtained, and these show great uniformity, the variation in size being inside of rather narrow limits.

The new type of nozzle is the form in which the spray is in a plane inclined at the angle of 45° from the plane of the impinging streams, but between that and the usual style, having the spray in a plane 90° from that of the streams, there is the possibility of any number of intermediate forms that present any desired degree of uniformity in the size of the drops. Should a compromise nozzle giving a driving spray with greater uniformity than in the existing nozzles be desired, it can readily be constructed. The same could be secured by a disproportion between the sizes of the two streams, and in this case the coarser portion would be at one edge instead of at the center of the fan. This form might be desirable for some spot-spraying for scale insects, and it might be desirable to have a means of controlling the size of one of the streams.

WHERE THE NEW NOZZLES ARE IMPRACTICAL

Because the spray must first be separated into two streams in this type of nozzle it becomes particularly liable to clogging and should not be used for any spraying where there is any such tendency—e. g., with Bordeaux mixture.

Most of the spray materials now used, however, are clear solutions and give no trouble in the nozzle.

LONG- AND SHORT-DISTANCE NOZZLES

When the angle is widest between the impinging streams, the angle of the fan is likewise widest, the drops finest, and the carrying distance of the spray the shortest.

An acute angle between the impinging streams produces a very narrow spray which carries a longer distance, but may perhaps finally reach nearly as great a width as that of the rapidly spreading short-distance spray.

Some prefer a long-distance nozzle and use it close to an object, as where spot spraying on a tree trunk is desired. The new type of nozzle lends itself very readily to adjustment to any degree of distance, from the shortest to nearly the longest found in spray nozzles.

ADJUSTMENT

Any form of two-stream nozzle, like that known as the calla, or lily, nozzles, can be quickly converted into a nozzle of the new type by the use of a reamer, slightly enlarging the two apertures on opposite sides by working the instrument obliquely to the surface of the nozzle and trying it from time to time until the spray sheet stands at 45°.

The same process will enable one to adjust a nozzle at any time should it wear irregularly enough to change the angle of the spray fan. The shape of the fan is a good index of the correct adjustment. If the angle is just right, the fan is triangular; if less than 45°, it is shortest in the center and the spray is coarser at the ends. If the angle is more than 45°, the fan is longest in the center and the spray coarsest at this point.

With care the reamer can be so used as to effect the change in the stream without enlarging the hole at the surface, and, therefore, not changing the volume of discharge. It may be possible to change the angle of the spread of the fan by reaming out beneath on the side adjacent to or opposite the other hole. One should continually try a nozzle while adjusting it, so as not to carry the work too far.

SUMMARY

(1) A new principle employed in nozzle construction will produce a flat spray with the qualities of a cyclone nozzle.

(2) A uniform sheet of water breaking along its edge produces drops of uniform size.

(3) A flat spray is more easily directed and produces a more uniform distribution than the cone of spray from a cyclone nozzle.

(4) Uniformly fine drops of spray aid in securing uniformity of distribution.

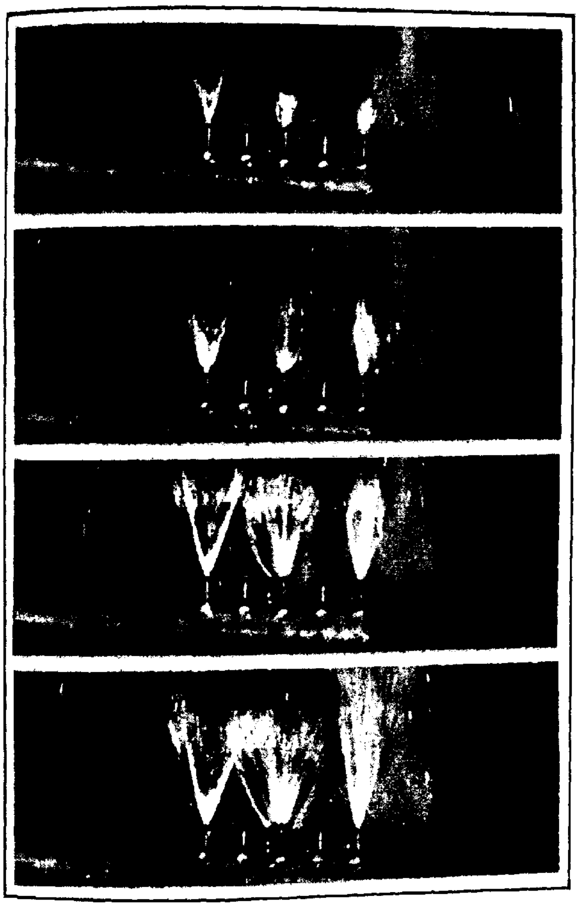
(5) The new nozzle allows some variation in size of spray.

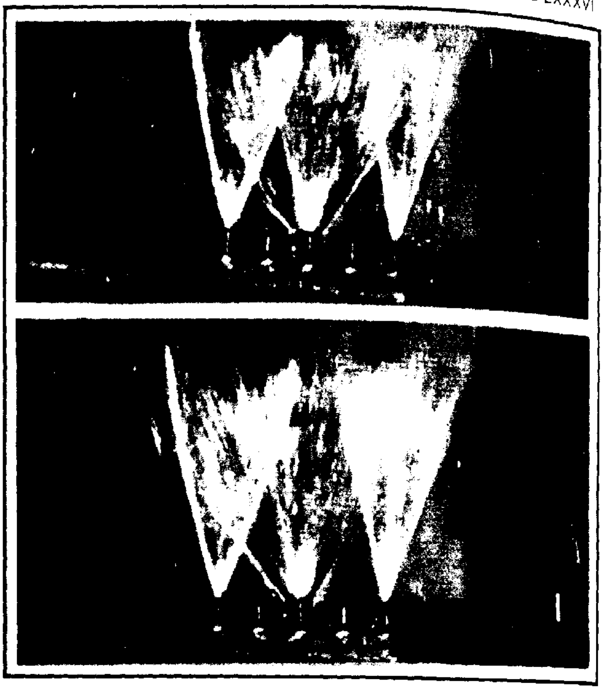
(6) It also may be made into a long- or short-distance nozzle.

(7) It can be easily constructed by modifying existing nozzles and may be adjusted if it becomes worn.

PLATE LXXXV

The beginning of the spray from three kinds of nozzles, as photographed with a moving-picture camera.





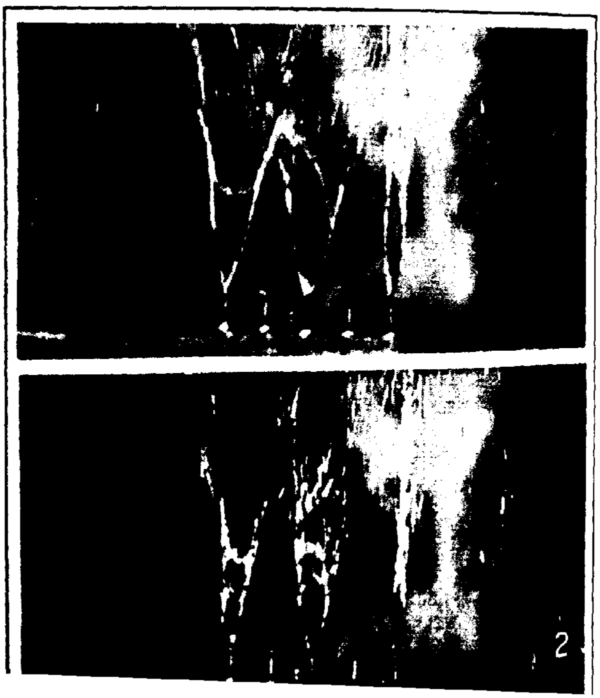


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PLATE LXXXVI

Fig. 1.—The appearance of spray from three kinds of nozzles as full pressure is applied (a continuation of Plate LXXXV).

Fig. 2.—Two stages at the end of the spray as the pressure is reduced.

A NEW INTERPRETATION OF THE RELATIONSHIPS OF TEMPERATURE AND HUMIDITY TO INSECT DEVELOPMENT

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INTRODUCTION

Upon the proper interpretation of the laws of climatic control of life rests the solution of many practical problems, and inasmuch as all plant and animal life reacts to climate in the same general manner it is apparent that the study of the climatic control of insect development may throw light upon the problems of all other forms of life. It has been apparent to some workers in the field of ecology that our so-called laws of effective temperature were deficient in many respects. A large number of phenomena were not properly explained by any known theory. It is with the hope that the present interpretation may come closer to the truth that this paper has been prepared.

Biologists for years were laboring with the theory of a fixed zero of effective temperature for all life, and only recently was it accepted that each species might have a different zero. It has been the custom to determine the thermal constant for any given activity by multiplying the number of effective degrees accumulated above the effective zero in daily units of mean temperature by the time in which the given phenomenon took place. The noneffective low temperatures were eliminated, but not the time in which they were experienced. Inasmuch as most workers were located in north-temperate climates, where high noneffective temperatures seldom occur, it had not occurred to them that some high temperatures might not be effective and that there was another boundary to the effective zone besides the zero. These high temperatures and the time in which they are experienced must be eliminated. In addition to all of these errors in method, there has been no correlation of the humidity factor until very recently, although now many workers are trying to solve the part played by this factor.

The principal data upon which the writer has based his studies include records of thousands of individual boll weevils (*Anthonomus grandis* Boh. and *A. g. thurberiae* Pierce), made by the members of the boll-weevil force under the direction of Mr. W. D. Hunter and the writer at various localities in Texas, Louisiana, and Arizona throughout the period of years from 1902 to 1915. At each place where biological notes were made a thermograph-hygrograph record was kept, and this record was

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checked twice daily by maximum and minimum thermometer and sling-psychrometer readings. The means of temperature and humidity are based upon these records. In addition to the natural records, a series of artificial-cold experiments were conducted at various times, and the writer recently conducted an extensive series of artificial-heat experiments with definite humidity control in order to determine the effects of heat.

EXPERIMENTAL METHODS

Before venturing to present this new interpretation the writer has thoroughly discussed it with many prominent workers, and it is now proposed for more extensive criticism and elaboration.

To express the relationship of the two factors, temperature and humidity, to insect metabolism, development, and activity, a temperature scale may be marked off on the vertical line of a sheet of plotting paper and a humidity scale from left to right on the horizontal line. There are, for any given insect, definite boundaries of atmospheric temperature and humidity within which the life of the species revolves. There is a temperature below which, even for the shortest time, life is impossible—the absolute minimum fatal temperature. There is also a temperature above which, even for a moment, life is impossible—the absolute maximum fatal temperature.. Absolute dryness is more or less prohibitive of life and so is absolute humidity, or saturation, although some insects may be adapted better to withstand extremes of humidity than others. It is quite possible that the boundaries of humidity may be 0 and 100 per cent, or infinitesimally close thereto.

The diagrammatic figure sought, however, has four definite absolute boundaries—the maximum and minimum temperatures and humidities.

Within the limits which we have thus defined there exist conditions under which all the activities of the species reach their maximum efficiency. It has been conceived by most writers that this maximum efficiency was reached at a definite point known as the optimum. It seems more likely that it will prove to be a zone of humidities and temperatures of more or less restricted area. A careful study of the records of any species, charting for the time required for each activity and the temperature and then similarly for humidity, will disclose temperature and humidity points of maximum efficiency. With the boll weevil these points lie approximately near 83° F. and 65 per cent of relative humidity.

ZONES OF CLIMATIC RELATIONS

At any ordinary humidity, starting with the absolute minimum fatal temperature, as the temperature increases a longer and longer time of exposure is required to kill, until a point is reached at which life continues indefinitely. This zone of temperatures has been called the zone of fatal temperatures.

As the temperature continues to rise it passes through a zone of ineffective temperatures, known commonly as the zone of hibernation, which the writer will shortly prove to be an inappropriate term. At the lowest temperatures in this zone complete dormancy without metabolism is found; but as the temperature increases a gradual approach to sensibility is noted, first metabolism, next movement, and then the necessity of feeding. The point at which metabolism or growth begins at a given humidity is the zero of effective temperature.

As the temperature increases above this zero the activity is at first very sluggish, but becomes more and more active until the so-called optimum is reached, and from this point upward the temperatures cause less and less activity, inducing stupor and finally sleep or coma.

At the point of coma begins the zone of ineffective temperatures formerly known as estivation. With the increase of temperature sleep becomes more and more sound until a point is reached at which death occurs after long exposure. At this point begins the zone of high fatal temperatures at which death occurs at shorter and shorter periods until it is instantaneous at the absolute maximum fatal temperature. This completes the vertical cross section of the figure desired. A statement regarding these vertical zones was first published by the Bureau of Entomology in 1912.[1]

In the past, however, the fact that a similar horizontal cross section at any temperature can be made, starting at absolute dryness and reading toward absolute humidity, has not been recognized. In this manner are shown zones of fatal dryness, dryness causing stupor, increasingly effective humidity, the most effective humidity, decreasingly effective humidity, excessive humidity causing drowsiness, and finally fatal humidity, at least under certain conditions of exposure.

In the case of the boll weevil the resulting figure is a series of concentric ellipses centered about the optimum and with diagonal axes. On the accompanying diagram the main details of the relations of temperature and humidity to the boll weevil are brought out. Only a few of the more salient records are included. The development in buds (cotton squares) is based upon hundreds of individual records, but is not reported in detail. The outer lines are much less definitely located than the inner ones, but whatever their actual location the picture would be substantially the same.

EFFECTIVE TEMPERATURE

Workers who have used the zero of effective temperature in their studies will note that, according to the present theory, the zero when charted is an elliptical curve representing a different point at each degree

[1] Hunter, W. D., and Pierce, W. D. Mexican cotton-boll weevil. 62d Cong., 2d Sess., Sen. Doc. 305 (U. S. Dept. Agr. Bur. Ent. Bul. 114), p. 125–128. 1912.

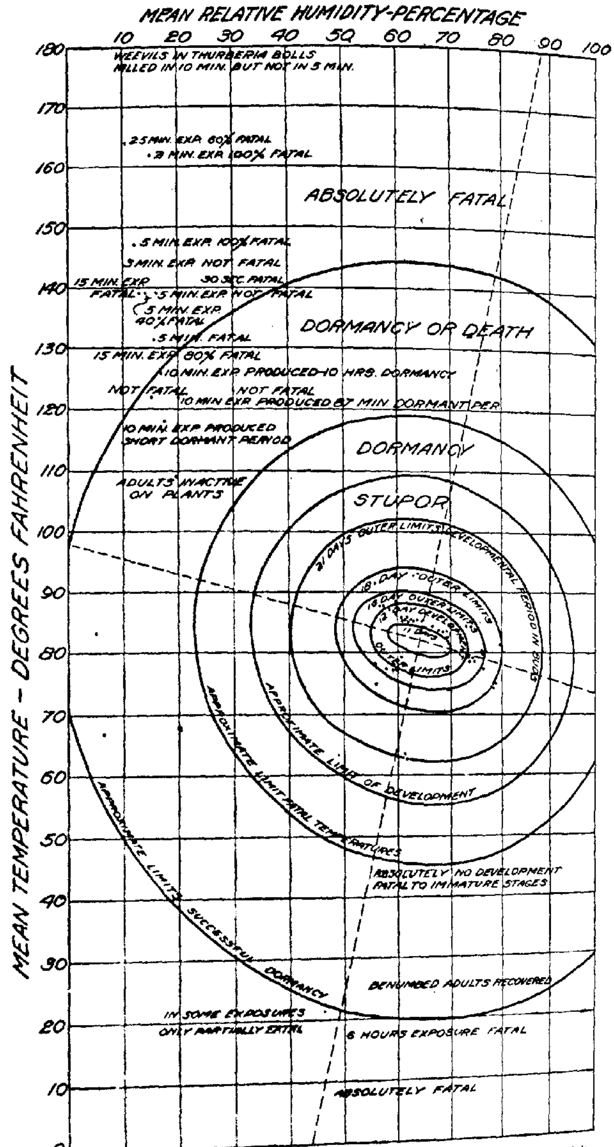

FIG. 1.—Graph showing the relations of temperature and humidity to cotton boll-weevil activity

of humidity. Because of the difficulty of computing this zero, the writer has been requested to describe his method of computing effective temperatures.

The first step is to tabulate all records of a given mean percentage of humidity on a single sheet. The zone of effective temperatures must be worked out separately at each degree of humidity. Only by a laborious series of testings can the first zero be approximated, unless the worker finds it by a fortunate chance. The total effective temperature is the criterion by which we finally know when we have rightly defined the limits of the zero. This is known as the thermal constant and is the multiple of the mean of the effective temperatures (between the zero and the absolute), figured in day units, by the time in which these effective temperatures were experienced. Noneffective temperatures, whether high or low, and the time in which they were experienced must be eliminated. The zone of effective temperatures will be finally reached for any given humidity when the

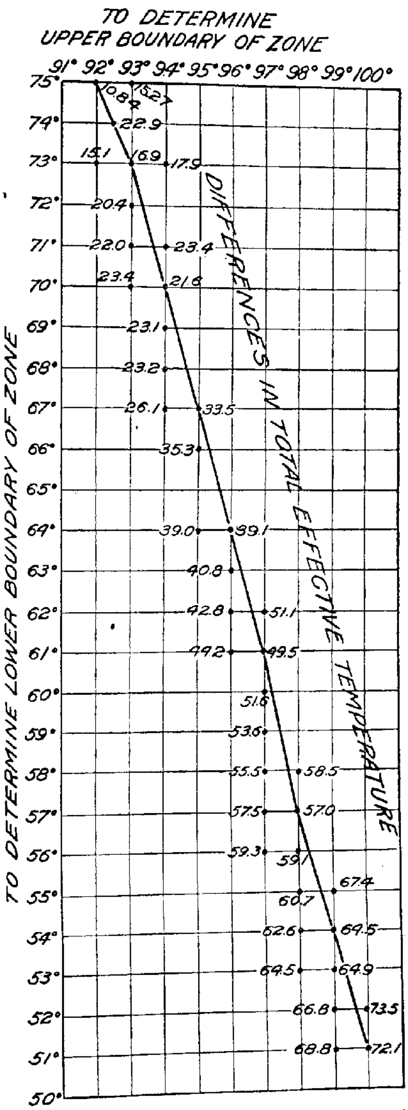

FIG. 2.—Graph showing the method of determining the zone of effective temperatures at a humidity of 56 per cent.

difference in the total effective temperatures is reduced to a minimum. At the start some arbitrary zero must be chosen and the effective temperatures computed above this. Then it is necessary to remove degree by degree at the top or bottom and note each time whether the difference in the total effective temperatures becomes larger or smaller. This process may be charted so that the general tendency can be seen. The figures found in the writer's attempt to establish the zone of effective temperatures for the boll weevil at 56 per cent humidity will illustrate the manner in which the points desired were ascertained. These results are presented in figure 2, and it will be seen that the first tentative zone chosen was 51° to 100° F. By much testing it was narrowed to within the limits of 75° to 92° F., for which the optimum is practically 83.5°.

Having obtained the limits of the zone, the records of development in cotton squares at a mean humidity of 55.9 per cent to 56.9 per cent, made at Victoria, Tex., in 1913, by Mr. B. R. Coad, of the Bureau of Entomology, are as shown in Tables I and II.

TABLE I.—*Records of development of Anthonomus grandis at Victoria, Tex., in 1913, at a humidity of 55.9 to 56.9 per cent*

Experiment.	Mean humidity.	Date of oviposition.	Time of maturing.	Actual period of development.	Number of weevils observed.		Total weevil days.	Actual temperature.		
					Male.	Female.		Absolute maximum.	Absolute minimum.	Mean.
	Per cent.			*Days.*				*° F.*	*° F.*	*° F.*
1	56.1	July 27	Aug. 9	13	6	2	104	104	73.2	88.2
2	56.4	July 26	Aug. 8	13	1	3	52	104	73.2	88.2
3	56.6	July 27	Aug. 10	14		1	14	104	73.2	88.2
4	56.9	July 27	Aug. 11	15		1	15	104	73.2	88.2
5	55.9	May 22	June 7	16	1		16	95.5	54.5	78.2
Mean	56.2				Total. 8	7	201			

TABLE II.—*Records of development of Anthonomus grandis at Victoria, Tex., in 1913, in the zone of effective temperatures, 75° to 92° F.*

1[a]	2[a]	3[a]	4[a]	5[a]	6[a]	7[a]	8[a]	9[a]	10[a]	11[a]
Experiment.	Number of weevils.	Mean humidity.	Humid time units.	Period experiencing effective temperature.	Total effective weevil days.	Mean effective temperature.	Effective thermal units.	Mean daily effective temperature units.	Total effective temperature.	Humidity plus effective temperature.
		Per ct.		*Days.*		*° F.*			*° F.*	*° F.*
1	8	56.1	448.8	8.19	65.52	83.8	670.4	8.8	72.0	139.9
2	4	56.4	225.6	8.18	32.72	83.8	335.2	8.8	71.98	140.2
3	1	56.6	56.6	8.86	8.86	83.6	83.6	8.6	76.1	140.2
4	1	56.9	56.9	9.52	9.52	83.7	83.7	8.7	82.82	140.6
5	1	55.9	55.9	9.95	9.95	82.6	82.6	7.6	75.6	138.5
Total	15		843.8		126.57		1,255.5	8.7	73.3	139.9
Average		56.2		8.43		83.7				
Difference								1.2	10.84	2.1

[a] Column 4 is product of columns 2 and 3. Column 5 is computed from the actual records. Column 6 is the product of 2 and 5. Column 8 is the product of 2 and 7. Column 9 is 7 minus the zero (75° F.). Column 10 is the product of columns 5 and 9. Column 11 is the sum of columns 3 and 7.

From these tables it will be seen that the effective period of development is from 8 to 10 days, averaging 8.43 days, while the actual development ranged from 13 to 16 days. It is noticeable that in all of the records the maximum as well as the minimum temperatures ran outside of the zone of effective temperatures. The total effective temperature ranged from 72° to 83° F., with 73.3° as the weighted mean and with a total difference of only 10.84°, a very small difference.

It is not necessary in this paper to give the further details of the zone of effective temperatures at other humidities. The determination of the zone for the next percentage of humidity is much less difficult, because it must be just a little narrower or a little wider than already determined. As the axis is diagonal, the upper and lower bounds will depart at a different rate. After several points have been determined, the axis can be located and then the figuring becomes very simple. It must be noted that every hour of effective temperature has its cumulative effect, even in the winter time.

ZONE OF INACTIVITY

One of the results of the acceptance of the present interpretation will be the necessity of discarding the conception of separate zones of hibernation and estivation. Physiologists have demonstrated that the effects of heat and cold on metabolism are alike. The writer has frequently noticed in field work the impossibility of differentiating between a frozen and a heat-killed boll-weevil larva. Prof. G. G. Becker, of Arkansas Agricultural College, several years ago observed that the fall army worm, *Laphygma frugiperda* S. and A., had two periods of activity and two of inactivity every day in the hot days in the Ozarks. Activity began in the morning and continued until the early part of the afternoon, when the heat caused the worms to be inactive for several hours. They then again became active during the early hours of the night, but the nights were cold and the worms became inactive until morning. The phenomena of a year were reproduced day by day. Inactivity due to cold in the summer time can not properly be called hibernation.

In Arizona the boll weevil is now native on wild cotton (*Thurberia thespesioides*). It normally breeds in the bolls in the fall, becoming adult by December 1, but remains in its cell throughout the cold winter and the warming spring. In some canyons there is a spring rainy season and *T. thespesioides* has a spring fruiting season. In these localities the moisture also releases the weevils from their cells and they begin breeding. A dry season follows and the weevils go to sleep. In other canyons the spring is not wet and the plants and weevils are inactive until the regular rainy season in August, when the long rest is broken. In some canyons the weevils therefore have two resting periods during the year, and in other canyons they are at rest from fall until summer. It not infrequently happens that the August rainy season does not materialize, and under

such circumstances the weevils stay in their cells and the plants remain dormant until the next year or perhaps for several years. As evidence of this the writer kept several of these weevils over 500 days without food or water, and one lived 626 days, dying only when moisture invaded the room where it was kept.

Hunter, Pratt, and Mitchell[1] record the unusual ability of larvæ of *Hermetia chrysopila* Loew, a cactus scavenger fly, to withstand long periods of drought. Larvæ in various stages of development were kept for more than 15 months without food and developed readily later when food was supplied. The very leathery integument seems to protect the insect against desiccation, and in other ways the larva has evidently adapted itself to long periods of waiting for favorable food, which, in the arid regions, depends upon the infrequent rains. Both of these instances are more properly resting periods due to dryness than to cold or heat.

NOMENCLATURE OF CLIMATIC EFFECTS ON LIFE

As charted, there are three elliptical zones which express the three principal effects of climate on life, viz, activity, inactivity, and death. The zone of activity may be known as the "thermopractic" zone (θερμός, meaning heat, plus πρακτικός, meaning effective). The zone of inactivity may be known as the zone of "anesthesia" (ἀναισθησία, meaning insensibility). The zone of death may be known as the "olethric" zone (ὀλέθριος, meaning deadly). The region of greatest activity may be known as the "practicotatum" zone (πρακτικώτατον, meaning most effective).

Many phases of climatic effects have been differentiated, and medical literature abounds in words descriptive of these effects. For some effects no words are available. The writer has thought it best to present a complete and consistent system of nomenclature, based on the Greek, using all words already in the language, and only supplying new words where none are now available.[2]

It may be convenient to refer to the most effective temperature or the most effective humidity, in which cases we may use the words "thermopracticotatum" or "hygropracticotatum."

The awakening from sleep is termed "anastasis" (ἀνάστασις). We can therefore speak of "thermanastasis" and "hygranastasis," depending on whether the awakening is caused by a change of temperature or a change of humidity.

Heat, moisture, dryness, or cold added to the "practicotatum" will cause sluggishness. We have to indicate this condition the term "nochelia"

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[1] Hunter, W. D., Pratt, F. C., and Mitchell, J. D. The principal cactus insects of the United States, U. S. Dept. Agr. Bur. Ent. Bul. 113, p. 38–39. 1912.

[2] New Standard Dictionary. 1913.

Gould, G. M. An Illustrated Dictionary of Medicine, Biology and Allied Sciences . . . ed. 6, with . . . Sup . . . 1633, 571 p., Philadelphia, 1910.

(νωχέλεια, meaning sluggishness) and can show the type of sluggishness by the addition of a prefix, as "thermonochelia," "hygronochelia," "xeronochelia," and "rhigonochelia."

At least three of these factors produce under extreme conditions a stifling sensation, and we may express this by the terms "thermopnigia," "xeropnigia," and "hygropnigia" (πνίγος, meaning stifling).

The stifling sensation ends in complete insensibility, or anesthesia, and this word may be modified to express the cause, as in the term "thermanesthesia," "hygranesthesia," "xeranesthesia," and "rhiganesthesia."

Death from heat is known as thermoplegia (πληγή, meaning stroke), while from excessive moisture it may be known as "hygroplegia," and from freezing, as "rhigoplegia." Death from drying is known as "apoxeraenosis" (ἀποξηραίνω, meaning to dry up).

The determination of locomotion by heat is called "thermotaxis," and movement brought about by heat is called "thermotropism."

Unusual sensibility to heat is called "thermalgesia" and "hyperthermalgesia." The ability to recognize changes of temperature is "thermesthesia," and its extreme is designated as "thermohyperesthesia," abnormal sensitiveness to heat "stimuli." Fondness for heat or requiring great heat for growth is called "thermophilic," while resistance to heat is called "thermophylic." Rapid breathing, owing to high temperature, is designated as "thermopolypnea," contraction under the action of heat as "thermosystaltic," adapting the bodily temperature to that of the environment as "pecilothermal," and a morbid dread of heat as "thermophobia."

The life after apparent death, called "anabiosis," is exemplified in such cases as that of the Hermetia larvæ mentioned above.

Pain from the application of cold is called "cryalgesia," abnormal sensitiveness to cold "cryesthesia," and a morbid sensitiveness to cold "hypercryalgesia."

PRACTICAL APPLICATIONS

Many practical measures will result from the further study of climatic relations to life. A few of these may be indicated.

One of the most effective measures for the control of the cattle tick is pasture rotation based upon the possible duration of life of the seed tick without an animal host. As this period varies with the season, it is necessary to know the climatic laws under which this species reacts.

The fall army worm advances across the country and again retreats in complete accord with changing temperatures. The proper fixation of the zone of effective temperature may make it possible to plan the planting of winter crops to avoid damage.

The cotton boll weevil must have food up to the time that it enters hibernation. Early harvesting and destruction of stalks before the low temperatures set in offer one of the most satisfactory methods of control.

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